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Winning photographs of the Moyra Eldridge Photographic Competition for 2005. Plates 2 & 3a&b Centre colour spread.

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The Geoff Brown Memorial Lecture: Volcanic eruptions into Iceland's glaciers

Dr Dave McGarvie, (Staff Tutor, Faculty of Science, OU Yorkshire Region)

Author's Note.
Although this is an abridged account of the memorial lecture, some material has also been added to help those who were not at the lecture (and who did not see the many illuminating images) to gain better insight into these unusual eruptions.

My talk is about volcanic eruptions into Iceland's glaciers. (Like Icelanders I use the term 'glacier' very loosely, to include all icy coverings – ice sheets, ice caps, valley glaciers, and so on.) Of relevance to this particular talk is that I went with Geoff Brown to Iceland on four trips between 1985 and 1988, and in those were sown the seeds of the research that I am doing at the moment.

The talk will cover the following:

- An introduction to Iceland.
- Working with Geoff at the Askja volcano.
- What a basalt 'tuya' is and how it is formed (i.e. a large basalt eruption into thick ice).
- The 1996 Gjálp eruption (an example of a small basalt eruption into thick ice).
- The 2004 Grimsvötn eruption (an example of a small basalt eruption into thin ice).
- Thick-ice rhyolite eruptions at the Kerlingarfjöll mountains.
- Thin-ice rhyolite eruptions at the Öraefajökull stratovolcano.

Some basic facts about Iceland

Iceland's highest point is just over 2km above sea-level, the oldest rocks are *c*.16 Ma old and there is an eruption every five years or so. About 90% of Iceland is basalt and about 10% is rhyolite. Iceland is also notable because it is building new land, and during the 1960s the island of Surtsey was created off Iceland's south coast. Of particular relevance to this talk is that once it emerged above the sea surface and seawater was denied access to the vent, subaerial basalt lava flows were able to pour out over the new island till they reached its coast and flowed into the sea. Here they quenched and fragmented, and the fragments tumbled down the underwater slopes to form breccias. This process also occurs during large basaltic eruptions into thick glaciers, and its significance will become apparent later.

Iceland is home to the massive glacier of Vatnajökull, into which all the other ice in Iceland and Northern Europe could fit with room to spare. One of my heroes, a chap called William Lord Watts, trekked across Vatnajökull in 1875 with five Icelandic guides. It is fascinating to compare and contrast his explorations and adventures with those of modern-day fieldwork in Iceland. A reconstruction of his route across Vatnajökull shows that he passed near to what would one day become the 1996 and 2004 subglacial eruption sites at Gjálp and Grimsvötn, which we will cover later.

His food supplies were 'interesting' and somewhat different to those of modern-day expeditions: 100lbs of pemmican in skin bags; 15lbs of dried mutton; 15lbs of dried fish; 3 tins of Peek and Frean's meat biscuits; 50lbs of butter; 12lbs of gravy soup; 2lbs of cocoa; 6 tins of chocolate and milk; 10lbs of Danish ship-biscuits; and 4lbs of sugar.

As you can see, the diet was dominated by meat and fat, with very little carbohydrate. Yes – it looks like the forerunner of the Atkins diet. It is the cold of course. In a cold climate a lot of fat is exactly what you need to keep you going. The diet obviously worked because the Watts expedition was very successful.

Figure 1. Geoff Brown at Askja in 1985.

At Askja with Geoff

One of the other places visited by William Lord Watts was the remote volcano of Askja in the central highlands of Iceland. It is usually only accessible for fieldwork for about eight weeks each year, and I went there with Geoff on four trips from 1985-1988 (Figure 1). Geoff wanted to do geophysics at Askja, in particular to use gravity-meters to measure density variations in the crust to try and understand the subsurface structure of the volcano (looking for magma chambers etc). I was there as his Icelandic geology specialist, and he also asked me to challenge/correct the more wayward ideas of the over-imaginative geophysicists. Much of Askja is constructed of fragmental basalt formed during eruptions into glaciers, and this was the first time I had had a serious look at these rocks (Figure 2). The observations I made then remained with me until I rejoined the OU in 1996 and started thinking about

Figure 2. Examining fragmental basalt produced during a subglacial eruption at Askja.

Figure 3. Askja's two calderas – the water-filled 1875 caldera and the wall of the older and larger caldera in the background. In the right foreground is the small Viti crater.

doing some research again after a decade-long hiatus. So my time with Geoff at Askja played a key role in inspiring me to start working on the unsolved problems of volcanic eruptions into glaciers.

Askja has two calderas (Figure 3); the largest (and also the older of the two) is about 8km in diameter. An eruption in 1875 (rhyolite and basalt) created the smaller and younger (*c.*4km diameter) caldera, which now contains Iceland's deepest lake (220m deep). Only one of the 1875 vents escaped the caldera collapse, and this forms a small crater called Viti (which is Icelandic for 'Hell' or 'mouth of Hell'). Viti is a common name for eruptive vents in Iceland. We bring William Lord Watts back into the story now, because he visited Askja in 1875 and described the tail end of the eruption. Here is an extract from his book *Across the Vatna Jökull*:

"…beneath us lay a pandemonium of steam and hideous sounds…the most hideous shrieks, groans, booming and screaming sounds rose from all parts of this terrible depression, the bottom of which was now utterly obscured. The sides of the crater were evidently falling in, and huge wide cracks, even where we stood, showed us that our position was not altogether a safe one."

Most people would not have lingered in such a potentially hazardous situation (especially if they'd read and signed a modern-day Risk Assessment). But our intrepid explorer merely wrote:

"So we lit our pipes and waited until we could obtain a better view."

Sadly he did not get a better view, otherwise we would have learned a great deal more about the end of the 1875 eruption – aspects of which are still poorly understood.

A basalt tuya

A distinctive landform found throughout Iceland, which is characteristic of eruptions into glaciers, is a 'tuya', which is a large and steep-sided mountain, often with a flat top. (Some people call them table mountains.) Detailed research on tuyas has provided insight into what happens when large basaltic eruptions take place beneath thick ice.

From Askja one can see a basalt tuya called Herdubreid (Figure 4), which is a spectacular mountain rising about 1100m above the surrounding terrain, with a summit plateau about 2.5km in diameter and a volume around 9km^3. To construct a basalt tuya like

Figure 4. On the outer slopes of the Askja volcano. Dark ribbon is the 1961 basaltic lava flow from the most recent eruption. The prominent mountain is Herdubreid – a tuya formed during a large basaltic eruption into thick ice. The ice level was at least as high as the prominent break of slope over half way up the left-hand side.

Herdubreid requires a large eruption into very thick (*c.*1.5km) ice. The pronounced vertical construction of Herdubreid is due to thick ice confining the escape of erupting basalt. Everywhere the basalt tries to escape to it meets either ice or meltwater, and so it quenches and has to build upwards. (Without confinement by ice, such a large basalt eruption would simply produce a broad low-angled shield volcano (Figure 5), and there are many of these throughout Iceland's active rift zones.) At the top of Herdubreid (Figure 6) there are pronounced sub-horizontal layers which are subaerial basalt lava flows which have *not* come into contact with either ice or meltwater. Now this seems puzzling given that this

Figure 5. An Icelandic shield volcano. The same type of eruption forms a basaltic tuya when thick ice is present.

edifice was constructed within a glacier, but an important clue comes from a series of deposits found immediately below the subaerial lavas: these are foreset breccias derived from the fragmenting of these subaerial basalt lavas. In essence the subaerial basalt lava flows entered a meltwater moat surrounding the growing tuya, where they quenched, fragmented, and tumbled down the underwater slopes over earlier breccia packets. The distinct boundary between the sub-horizontal (subaerial) lava flows and

Figure 6. The 1100m high basaltic tuya of Herdubreid formed by ice confinement within a glacier, contrasts with the unconfined subaerial basalt lava flows in the foreground.

the steeply inclined foreset breccias is called the 'passage zone', which is essentially a fossil water level (i.e. the height of the meltwater lake within the glacier). Think back to our earlier description of basalt lava flows entering the sea at Surtsey: this provides us with a clear image of what must have happened at the top of Herdubreid. This is the closest visualisation we get, because nobody has ever observed a tuya-forming eruption. One of the volcanologists who has played a leading role in using field observations – mainly in Antarctica – to build up a widely accepted model of tuya formation is John Smellie (pronounced 'smiley'), of the British Antarctic Survey. John works with me on a number of subglacial volcanism projects.

The 1996 Gjálp eruption

The 1996 Gjálp eruption at Vatnajökull was a brilliant learning opportunity for volcanologists working on subglacial eruptions because no-one had ever properly investigated an eruption into 'thick' ice before. (At Gjálp the ice was *c.*450-750m thick.) Even ten hours after the start of the eruption the only visible sign that an eruption was taking place was a line of ice cauldrons (Figure 7, saucer-shaped depressions in the ice surface *c.*1-2km in diameter) which were deepening as ice melted and drained away at the eruption site at the glacier base. The behaviour of the ice during

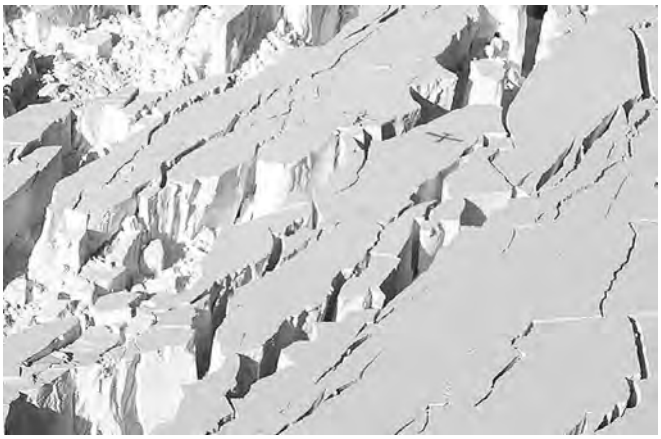

Figure 8. Brittle failure of the upper *c.*150m of ice during the 1996 Gjálp eruption. (Note the aircraft at top-centre, for scale.)

the eruption was fascinating, because whereas the upper *c.*150 m of ice deformed in a brittle fashion (with spectacular crevasses (Figure 8)), the lower *c.*450m deformed in a ductile fashion and flowed towards the eruption site, replenishing ice that was being melted by the eruption. (This process of ice replenishment during 'thick' ice eruptions means that these eruptions have the potential to melt larger volumes of ice, which in turn increases the hazard potential when the meltwater eventually escapes, typically as a sudden and large flood.) The name Gjálp comes from a female Frost Giant of that name, and the precise reason why this name was chosen for this particular eruption is little known outside Iceland.

When subglacial eruptions break through to the ice surface and reach the atmosphere they are called 'emergent', and it only took Gjálp 31 hours to become emergent. The (hidden) volcanic landform produced by the Gjálp fissure eruption was a linear ridge about 6km long and up to 500m high, not too dissimilar in shape to a bar of Toblerone. The Gjálp subglacial basalt ridge is typical of the many such ridges (Figure 9) that occur throughout Iceland's active rift zones. The main rock type forming these ridges is a glassy fragmented basalt called hyaloclastite, (hyalo = glassy, clastite = fragmental). These hyaloclastite ridges are thought to be unique to Iceland, because they require the unusual combination of linear fissure eruptions into thick ice, and there are no other comparable environments currently on Earth.

Figure 7. Ice cauldrons (1-2km diameter) forming above the 1996 subglacial Gjálp eruption, which was taking place beneath c.600m of ice.

Figure 9. An exposed subglacial basalt hyaloclastite ridge, similar to the one produced during the 1996 Gjálp eruption.

The Gjálp eruption was quite small (*c*.0.5km^3) and lasted only thirteen days, but one notable surprise was that such a small eruption only took thirty-one hours to melt through over 600m of ice. The surprise is that such a high melting rate (calculated as 5000m^{3}s^{-1} over the first 4 days) meant that magma must have been fragmenting at depth, whereas it was anticipated that the high glaciostatic pressure of such thick ice would have favoured pillow lava effusion. (In short, the rate of heat transfer from pillows to ice/water was too slow to produce the high melting rate that was being observed, so a more efficient heat transfer mechanism involving magma fragmentation was required.) This was one of the new contributions of the Gjálp eruption to subglacial volcanology. The meltwater generated during the eruption (*c*.4km^3) eventually escaped about three weeks after the end of the eruption as a large flood (which Icelanders call a jökulhlaup), which had a peak flow rate of 45,000m^{3}s^{-1}. This is roughly equivalent to the normal flow rate of the Amazon at its mouth.

The November 2004 Grimsvötn eruption

In November 2004 a 'thin' ice eruption occurred at the Grimsvötn volcano, which is also within the vast Vatnajökull glacier. Grimsvötn has a caldera filled with a subglacial lake on which floats 150-200m of ice. One wall of the caldera lies permanently above the ice and forms a pronounced ridge. A powerful geothermal system (driven by an active magma chamber) continuously supplies the subglacial lake with meltwater until a high-enough water level is reached that causes an ice barrier to fail and releases much of the lake water as a sudden flood. The subglacial lake drained rapidly in November 2004 and the sudden pressure release above the magma chamber triggered a small eruption. (This process of rapid lake drainage followed by an eruption has happened a number of times at Grimsvötn.) The thin ice at Grimsvötn (<200m) in combination with the exposed caldera wall means that these eruptions become emergent very quickly, and the November 2004 eruption became emergent almost immediately (Figure 10). (At this point in the talk a DVD was shown which contained both aerial footage of the eruption and footage shot by two Icelanders who drove up to within a few hundred metres of the eruption. The ground-based footage is particularly spectacular and illuminating. The DVD was kindly loaned by Professor Magnus Tumi Gudmundsson of the University of Iceland, who has a highly-relevant connection to this talk because Geoff Brown examined and passed his PhD thesis.)

Figure 10. The November 2004 Grimsvötn eruption – which became emergent almost immediately.

Figure 11. The November 2004 Grimsvötn eruption site – five months after the eruption (marked by small tuff cone towards the bottom right).

This small eruption was very short lived – it only lasted a few days. Five months after the eruption it is hard to believe an eruption happened at all, as the only physical remnants are a small eroded tuff cone over the vent and some tephra carpeting the nearby ice (Figure 11). This really is an ephemeral landscape, and a few years from now the eruption site will be completely covered by the ice which is already flowing into the area. Most of the thin carpet of tephra on the surrounding glacier was covered by the winter snows that fell soon after the eruption.

Grimsvötn is Iceland's most frequently erupting volcano, but its eruptions are typically very small and short lived. Most of Grimsvötn's thin-ice eruptions rapidly become emergent, particularly those that are adjacent to the exposed caldera wall (such as the eruptions in 1998 and 2004). Eruptions that rapidly become emergent lose more heat to the atmosphere and consequently less heat is available for the melting of ice. However, the higher proportion of tephra that is ejected into the atmosphere leads to these small and short-lived eruptions being visually spectacular. Interestingly, the dynamic environment around Grimsvötn and the small volume of material erupted means that Grimsvötn's high eruption frequency was only discovered after boreholes within the glacier revealed the numerous but very localized ash layers associated with its many eruptions.

Returning again to William Lord Watts and his trek across the Vatnajökull in 1875 with his five Icelandic companions. You may have been wondering about the sleeping arrangements whilst they were stravaiging across the ice? Here they are:

"Our equipment...consists of a large sleeping-bag which would accommodate six of us - this was eight feet long, and five feet wide.... This bag was open at both ends, so that three could sleep with their heads one way and three with their heads the other. This gave us sleeping accommodation for six persons, with a weight of only sixty pounds. This bed, however, had its disadvantage, for if any one was taken with cramp, or dreamt of engaging in any particularly active exercise, its limited dimensions became painfully apparent…."

Thick-ice rhyolite eruptions at Kerlingarfjöll

In the central highlands of Iceland are the beautiful and colourful rhyolite mountains of Kerlingarfjöll. The area has some interesting history. Old Icelandic law meant that when someone was declared outlaw they were banished to the wasteland and it was forbidden to provide them with food or shelter (anyone who did so were themselves declared outlaw). One outlaw and his wife (Eyvindur and Halla) survived against all the odds for many, many years in the highlands, and they used the hot springs at Kerlingarfjöll (and other places in the highlands) as sources of heat to enable them to survive the long hard winters. He was nicknamed fjalla-Eyvindur (fjalla = mountain).

Figure 12. 315ka old subglacial rhyolite tuya at Kerlingarfjöll with well-formed lava cap and some exposure of the earlier-erupted fragmental pile beneath the extensive scree.

When a large rhyolite eruption takes place beneath thick ice a rhyolite tuya is formed that looks morphologically similar to a basalt tuya (although much smaller in volume, Figure 12). Of particular interest to those of us working on subglacial rhyolites is that some tuyas at Kerlingarfjöll have reasonable exposures of the early erupted material that lies beneath the lava cap. This early erupted material contains crucial information on how the explosively erupting rhyolite and the glacier were responding and interacting with each other, so it was a target for a research project.

Working on this early erupted fragmental material requires weeks of painstaking fieldwork, sometimes spending an entire day working on an exposure the size of a cupboard. Classical sedimentological techniques (e.g. graphic logging) help with classifying deposits and working out depositional environments and so on. Putting all the field observations and all the laboratory measurements together enabled a model to be constructed for the early stages of the formation of a subglacial rhyolite tuya.

Extensive water-magma interactions dominate the earliest stages, with the evidence for this being blocky and glassy shards (indicating rapid quenching), as well as low shard vesicularity (indicating inhibition of volatile escape). Successive deposits higher up the edifice show decreasing interactions with water accompanied by increasing clast vesicularities. In simple terms, the eruption becomes 'drier' as the edifice builds higher, to a stage when uninhibited volatile escape is able to produce highly inflated pumice. This was a surprise because with the good evidence that meltwater lakes are sustained at basalt tuya eruptions it was reasonable to consider that this also happened at rhyolite tuya eruptions; and yet our evidence clearly indicated the absence of such a meltwater lake. Interestingly the final stages of rhyolite tuya eruptions is similar to that of basalt tuyas, with lava effusions spreading over the fragmental pile and producing a lava cap (but of course with no passage zone at the rhyolite tuyas). The key discovery from our work at Kerlingarfjöll is that during subglacial rhyolite tuya eruptions the meltwater does not collect and pond at the vent, it drains away swiftly. A thick-ice rhyolite eruption has never been observed, but our work suggests that the jökulhlaup hazard from one would be minimal because there is no evidence of storage and sudden release of meltwater.

A separate project on subglacial rhyolites is determining the ages of tuyas from different Icelandic volcanic systems using Ar-Ar dating. One of the lessons we have learned from this is that appearances can be deceptive. At Kerlingarfjöll one youthful-looking rhyolite tuya has a well-formed and complete lava cap, whilst next to it another scruffy and old-looking tuya has a highly eroded lava cap with deeper exposures of the underlying early erupted material. On dating these it turned out that the youthful-looking tuya is the older, by about 110,000 years.

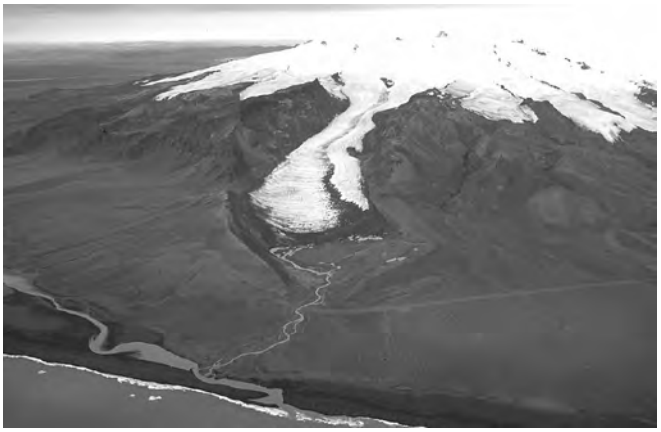

Figure 13. The Öraefajökull stratovolcano, showing its proximity to the coast. The field area is the east (right-hand) wall of the valley occupied by the Kviárjökull valley glacier. Note the spectacular *(c.*100m high) terminal moraine, which is Iceland's tallest.

Thin-ice rhyolite eruptions at the Öraefajökull stratovolcano

The Öraefajökull stratovolcano in south Iceland is a *c.*2km high and ice-covered stratovolcano, which includes Iceland's highest peak (Hvannadalshnúkur, 2119m) – a rhyolite dome on the rim of a 3-5km diameter summit caldera filled with up to 500m of ice at an average elevation of 1850m above sea-level. Our field area was the east wall of a deep valley glacier (Kviárjökull) that has cut into the south-eastern flanks of the stratovolcano (Figure 13). The lower exposures comprise thinly bedded basalt flows, with at least three thicker silicic units comprising the upper exposures. A number of dykes cut through the units, some of which feed relatively recent mafic lava flows. Of particular interest to our study was the presence of a thick pile of rhyolite tephra in one location, which we hoped would reveal the processes responsible for fragmenting rhyolite in this thin ice setting. Patterns of flow banding and columnar jointing in some unusual lava buttresses indicated that they had flowed down into ice tunnels melted into the sides of a valley glacier much thick-

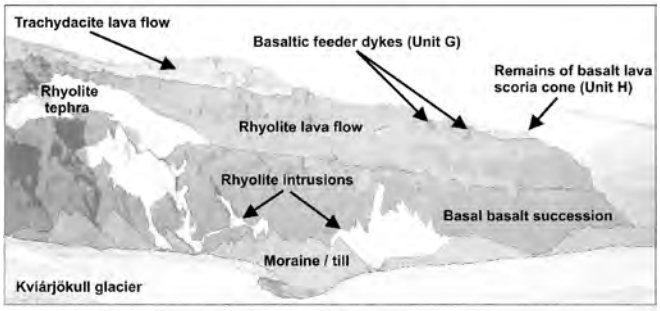

Figure 14. Geological units comprising the east wall of Kviárjökull.

er (by 500m) than the present-day glacier. The eastern wall was mapped (Figure 14) and the volcanological evidence from the various eruptive units was used to reconstruct the geological evolution of this flank of the stratovolcano. A tale of fluctuating ice thicknesses within the valley glacier unfolded.

We did not find any evidence of water being ponded, which is perhaps not surprising as the stratovolcano's steep slopes would have aided the drainage of water rapidly away from the eruption site. The rhyolite lavas we mapped originated from vents that are currently hidden beneath the ice higher up the stratovolcano. The rhyolite lavas are thicker than their subaerial counterparts, which suggests that even a thin carpeting of ice on the lower slopes was able to constrain and direct the flow of lavas. This may have assisted the (suspected) rapid construction of this stratovolcano, if even modest interactions with thin ice on its flanks can encourage the over-thickening of lava flows. Higher up (where ice is more substantial) the over-thickening effects would have been even more pronounced. A key finding from our research is that the evidence from ice-volcano interactions in eruptive units exposed in the east wall of the valley indicate that the valley was repeatedly filled with ice that was at times up to 700m thick (Figure 15). As the primary source of the ice feeding the valley glacier is the summit region, this could mean that this stratovolcano is particularly sensitive to the changing climatic conditions (e.g. temperature and precipitation) that trigger rapid ice accumulation.

At the moment Öraefajökull looks benign and beautiful, but it is merely sleeping until it next erupts. In 1362 there was a rhyolite eruption near the summit, which devastated what was once fertile, rich, and sheltered farmland at its foot. A combination of meltwater floods (jökulhlaups) and thick piles of rhyolite pumice destroyed the area and dispersed the thriving community that once lived here. Very recent research (summer 2005) by Icelandic geologists found new evidence that pyroclastic flows had been produced early in the eruption, which would have added to the

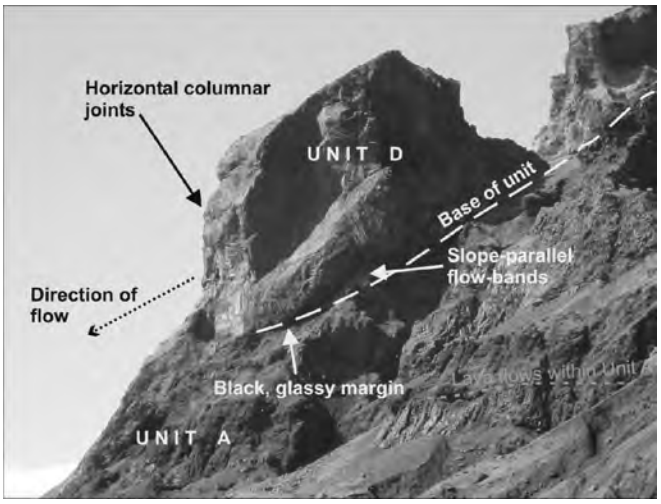

Figure 15. Annotated image of lava buttress on the east wall of Kviárjökull, interpreted to have flowed into an ice tunnel. This implies that the Kviárjökull glacier was much thicker at the time of this (Unit D) eruption.

destruction. The area was renamed 'Öraefi' after the 1362 eruption (Öraefi = wasteland or desert). The most recent eruption was a small basalt eruption in 1727. This eruption also generated devastating meltwater floods, and there are accounts of warm/hot water flowing out from beneath the valley glaciers. Here is an extract of an eyewitness account of the 1727 eruption.

"At nine in the morning three deep thunders were heard, louder than the other cracks, followed by water floods … of which the last was the largest, sweeping swiftly away horses and other domestic animals in their way. The glacier ice followed slowly down to the lowlands like molten metal poured from a smelter … the glacier broke up and some of the icebergs entered the sea but others remained stranded at the foot of the mountain" (Jón Thorláksson, Vicar)

This is a rare and powerful description of a jökulhlaup (meltwater flood) at an ice-covered stratovolcano. The warm water flowing along the base of a valley glacier both melts and lubricates the ice, enabling the glacier to flow more easily down to the foot of the stratovolcano. In two important respects the jökulhlaup hazard from Öraefajökull is greater than that of other volcanoes in Iceland: firstly, there is more unpredictability about the potential paths that jökulhlaups may take; and secondly, these meltwater floods occur so soon after the start of the eruption that there may be insufficient time for evacuation. It is fortunate indeed that eruptions from the Öraefajökull stratovolcano are quite infrequent.

An introduction to the pyroclastic rocks of the Bandas del Sur, Tenerife and field guide to the area around Tajao.

Duncan Woodcock

Introduction

The geology of Tenerife was once summarised by my father as "a pile of cinders surrounded by poorly made concrete". The "concrete" referred not to the plethora of holiday accommodation that was springing up at the time, but to the cream to pale brown-weathering road cuts that he passed as he traversed the south-east coastal area of the island known as the Bandas del Sur. These road cuts are exposures of the record left by a number of major explosive volcanic eruptions that characterised a particular stage in the geological development of Tenerife. The purpose of this paper is to describe these rocks in outline and then to present a field guide to a location that, to my knowledge, has not been described in detail before.

Geological History

The oldest volcanic rocks on Tenerife appear to be a late Miocene-Pliocene "shield building" phase that developed three separate but adjacent volcanic islands (Gill & Thirlwall 2003). The products of this phase comprise a thick sequence of horizontal lava flows. They are preserved in the three geographically separate massifs of Teno, Anaga and Roque del Conde (Figure 1), with their most dramatic exposure probably in the sheer cliffs at Los Gigantes. This phase was followed by a period of volcanic inactivity and erosion from 4.2 to 3.5 Ma (Gill & Thirlwall 2003).

The "post erosional" phase of activity began with the construction of a large composite volcano, the Cañadas stratovolcano, which developed a large magma chamber that allowed the production of felsic magmas by fractional crystallisation. Eruption of these felsic magmas resulted in a varied suite of pyroclastic deposits that outcrop in the Las Cañadas caldera wall and extensively in the Bandas del Sur area. These pyroclastic eruptions may have induced vertical collapse of the roof of the magma chamber to produce the present-day Las Cañadas caldera; although some authors favour production of the caldera by lateral collapse of the stratovolcano.

Recent volcanic activity has been dominated by the development of the post-caldera Teide-Pico Viejo stratovolcano which now dominates the northern half of the Las Cañadas caldera floor. The most recent activity in this area was a flank eruption in 1798 at Narices del Teide. The occasional whiff of volcanic gas around the Teide summit region indicates that it is still active.

Stratigraphy of the Bandas del Sur Group

This paper concentrates specifically on the products of the eruptions that occurred during the later development and subsequent collapse of the Cañadas stratovolcano. The deposits comprise mainly ignimbrites and pyroclastic fall deposits intercalated with minor lava flows plus patches of sandstone and conglomerate that record periods of rework of the primary volcanic material. In places an orange or brown palaeosol is present at the top of a unit, indicating a period of quiescence between major eruptions. With one exception the ignimbrites are all unwelded, although they are extensively indurated by the precipitation of secondary minerals, thus producing the "poorly made concrete" texture alluded to in the introduction. The exception, the Arico ignimbrite, displays a welded central section over some of its outcrop. A complete section through the Arico ignimbrite, which allows examination of the variation of welding through the ignimbrite, is displayed in the Barranco de Vijigua near Tajao and is described later in this paper.

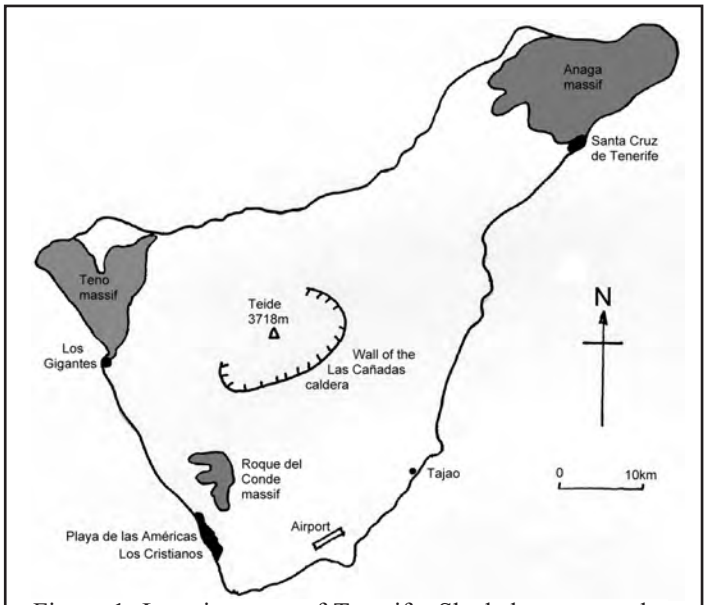

Figure 1. Location map of Tenerife. Shaded areas are the "Old Basaltic Series" – the remnants of the main shield-building phase of activity.

As might be expected, the pyroclastic units vary greatly in thickness and facies over the Bandas del Sur. For the ignimbrites, much of this variation probably arises from the initial depositional process. An ignimbrite is a particular type of deposit from a pyroclastic flow. Pyroclastic flows tend to follow the palaeovalleys and thus in sections at right angles to the flow they are thicker and more often welded in valley floors than on the valley sides. The subsequent erosion of a deposit, either by the passage of subsequent ignimbrite flows or by surface processes, will modify its thickness and distribution further.

The lateral variability in facies and thickness probably contributed to the rather untidy nomenclature that grew up during early attempts to understand the stratigraphy of the Bandas del Sur. More recently, an attempt has been made to trace units laterally over the whole area and thus to erect a revised stratigraphy for the Bandas del Sur Group that is more in line with current stratigraphic practice (Brown *et al* 2003). Thus a formation comprises a distinctive unit that records a major explosive eruption; ideally it is separated from adjacent formations by a palaeosol that records the intervening period of quiescence. A formation may comprise one or more members, each recording a distinctive phase of a major eruption. As an example, the Granadilla Formation comprises two main members: the Granadilla pumice from the Plinian phase of the eruption overlain by the Granadilla ignimbrite that records the subsequent eruption column collapse. Table 1 (based on Gill & Thirlwall 2003) summarises the stratigraphy of the upper Bandas del Sur Group. The stratigraphy of the underlying units remains to be formalised (Brown *et al.* 2003).

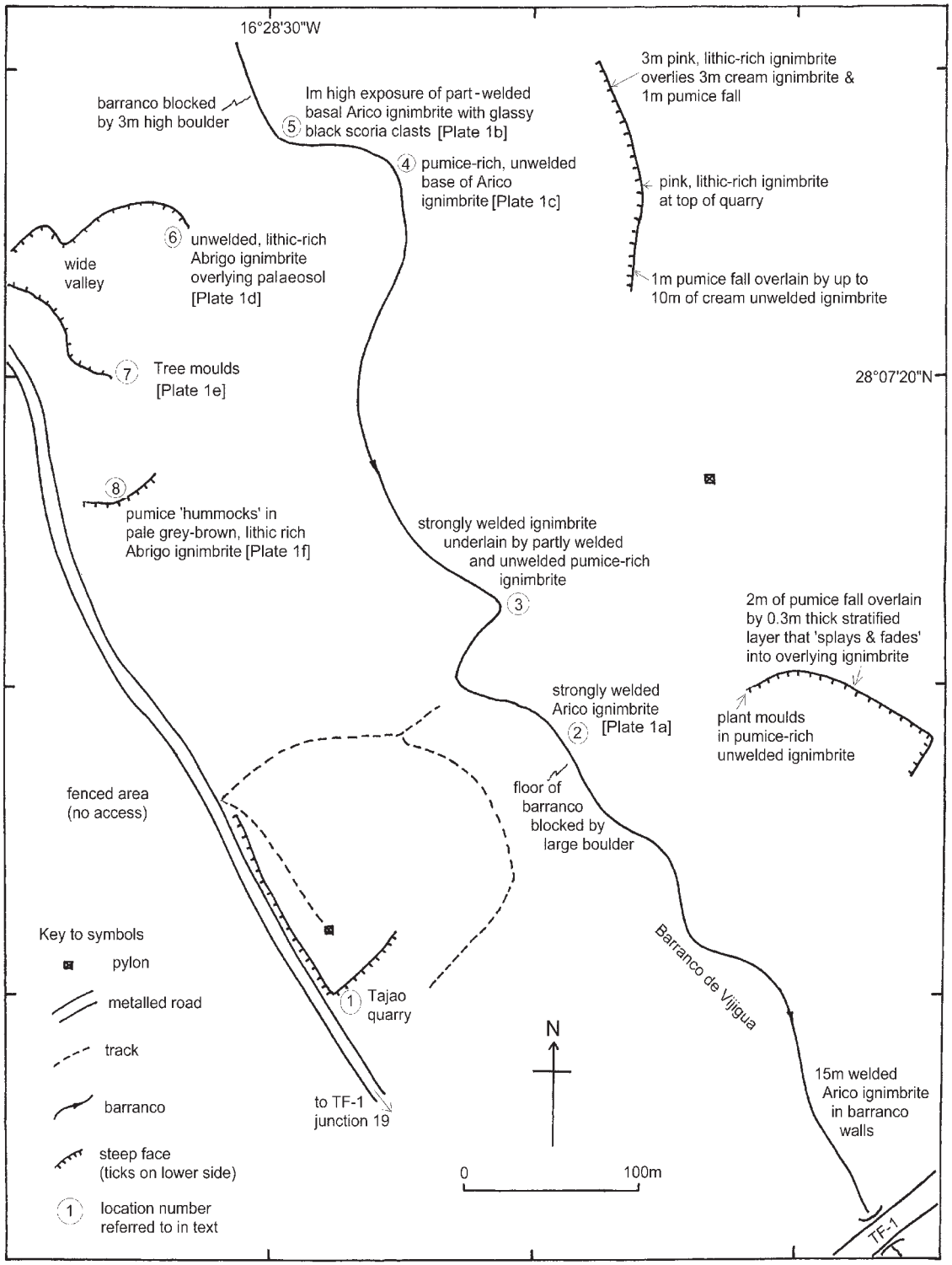
16°28'30"W
barranco blocked by 3m high boulder
1m high exposure of part-welded basal Arico ignimbrite with glassy black scoria clasts [Plate 1b]
5
4 pumice-rich, unwelded base of Arico ignimbrite [Plate 1c]
3m pink, lithic-rich ignimbrite overlies 3m cream ignimbrite & 1m pumice fall
pink, lithic-rich ignimbrite at top of quarry
1m pumice fall overlain by up to 10m of cream unwelded ignimbrite
6 unwelded, lithic-rich Abrigo ignimbrite overlying palaeosol [Plate 1d]
wide valley
7 Tree moulds [Plate 1e]
28°07'20"N
8 pumice 'hummocks' in pale grey-brown, lithic rich Abrigo ignimbrite [Plate 1f]
strongly welded ignimbrite underlain by partly welded and unwelded pumice-rich ignimbrite
3
2m of pumice fall overlain by 0.3m thick stratified layer that 'splays & fades' into overlying ignimbrite
strongly welded Arico ignimbrite 2 [Plate 1a]
plant moulds in pumice-rich unwelded ignimbrite
floor of barranco blocked by large boulder
fenced area (no access)
Key to symbols
pylon
metalled road
track
barranco
steep face (ticks on lower side)
1 location number referred to in text
1 Tajao quarry
to TF-1 junction 19
Barranco de Vilígua
N
0
100m
15m welded Arico ignimbrite in barranco walls
TF-1

Figure 2. Edited field sheet for the Tajao area north of the autopista (TF-1). Based on GPS survey of 3-4 February 2005. GPS datum: Pico de las Nieves.

Geological locations

The pyroclastic deposits of the Bandas del Sur Group cover much of the SE coastal plain of Tenerife where they are well exposed in coastal outcrops, road cuts, quarries and in the walls of "barrancos" – steep sided valleys that have been cut by infrequent but intense rainstorms. Most geological guides to Tenerife describe at least some exposures: the recent Geologists' Association (GA) guide (Gill & Thirlwall 2003) is the most up to date, while the field guide produced for the 1995 IAVCEI meeting (Marti & Mitjavila 1995) is probably the most comprehensive. An extensive literature on various aspects of the geology of the Bandas del Sur region has developed over the last ten years or so: this provides additional locality information, but the localities referred to are not always easy to locate. The purpose of the rest of the paper is to record details of my own observations in one area that shows a range of features particularly well.

The area around Tajao contains an outstanding section through the Arico ignimbrite together with numerous exposures of the overlying pyroclastic formations. Roadside exposures in this area are

Table 1 : Stratigraphy of the Upper Bandas del Sur Group

Caldera wall stratigraphy	Bandas del Sur stratigraphy	Age Ma
Diego Hernandez Formation	Abrigo Formation	0.17
	La Caleta Formation	0.22
	Sabinita Formation	
	Poris Formation	0.28
	Fasnia Formation	0.29
	Aldea Blanca Formation	
Guajara Formation	Granadilla Formation	0.6
	Abades Formation	0.6
	Arico Formation	0.67
Ucanca Formation	Eras Formation	

described in the GA and International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) field guides, although there is much that can be seen away from the road. This area is inconveniently cut in two by the Autopista del Sur (TF-1) – a dual carriageway that runs the length of the south of the island - it contains some splendid road cuts but it is illegal to stop. The areas to the north and south of Tajao are thus described separately.

(1) Tajao: area to the north of the autopista

Figure 2 comprises an edited version of my field sheet for this area. The complete thickness of the Arico ignimbrite is exposed in the Barranco de Vijigua. In addition there are numerous quarry faces and natural exposures in some of the overlying ignimbrite and pyroclastic fall units.

The faces of Tajao quarry (Location 1 on Figure 2) are described in both the GA (Locality 5.2) and the IAVCEI (Stop 17) field guides. This locality provides a good introduction to the units overlying the Arico ignimbrite and demonstrates well the lateral variability that might be expected elsewhere.

Figure 3 is a composite section through the Arico ignimbrite, together with locations on Figure 2 where the various features are best displayed – these are illustrated in Plate 1 a-c. The top of the welded section coincides with a marked break in slope between the narrow gorge below and the less steep slopes above. The welded section varies in thickness from 5m to more than 15m immediately north of the autopista. In my opinion, this section is far better exposed than the type section in the road cut at La Cisnera (GA guide Location 4.4b), and considerably more pleasant and less hazardous to study.

Exposures around the head of a valley (Location 6 on Figure 2) show the unwelded, lithic-rich Abrigo ignimbrite draping the underlying palaeotopography, which in places has a well developed palaeosol (Plate 1d). Moulds of tree trunks caught up in the pyroclastic flow are common, with an outstanding example at Location 7 shown in Plate 1e.

Immediately to the south, at Location 8, a 10m high cliff of Abrigo ignimbrite displays pumice "hummocks (Plate 1f). These distinctive dune-like features have a high concentration of large pumices, mainly in clast support, in an otherwise "normal" ignimbrite. The origin of these features is discussed by Pittari *et al.* (2005), who consider them to be original depositional features formed as a result of the tendency for large pumice clasts to be buoyant in some pyroclastic flows. Thus, large pumice clasts become segregated into the upper region of the flow and this highly mobile pumice-rich layer tends to advance ahead of the main flow. It is then deposited in dune-like bodies and then becomes overridden and mantled by "normal" ignimbrite when the main flow catches up.

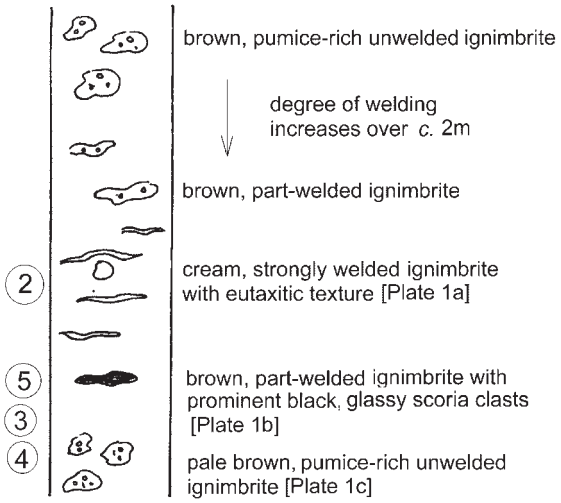

Figure 3. Schematic section through the Arico ignimbrite, Barranco de Vijigua. Not to scale. The numbers refer to location numbers on Figure 2. The unwelded top and transition downwards into the welded central section is best seen in the area south of the autopista.

(2) Tajao: area to the south of the autopista

Figure 4 comprises an edited version of my field sheet for this area. In contrast to the northern area, there is little of interest within the Barranco de Vijigua as the walls are often mantled with rock waste and tipped rubbish; however there are several quarries, road cuts and coastal exposures away from the barranco that provide much of interest. The exposures along the road into Tajao are described in the IAVCEI guide (Stop 30).

Two quarries on the NE rim of the barranco (Locations A & B on Figure 4) provide excellent sections through the top of the Arico ignimbrite, allowing the development of welding downwards to be studied in detail (Plate 1h). At Location B, the Arico ignimbrite is overlain by the Abades ignimbrite – a distinctive cream-weathering unwelded ignimbrite containing prominent black mafic scoria clasts.

Location C on Figure 4 contains excellent examples of plant moulds, with three clusters of holes adjacent to each other at the base of a cream-weathering unwelded ignimbrite (Plate 1g). These may have been produced when bushes like the example in Figure 5 were overwhelmed by the pyroclastic flow and pyrolysed by the hot ash.

Figure 6 is a photograph of the road cut at Location D on Figure 4. The exposure provides a good section through a variety of pyroclastic and reworked units, again demonstrating the lateral variability seen in Tajao quarry north of the autopista. Figure 7 comprises a stratigraphic section through the exposure. This location demonstrates well the difference between the primary pyroclastic flow deposits and those reworked by surface processes.

The pale grey unwelded La Caleta ignimbrite at Location E on Figure 4 contains two large isolated clasts of welded ignimbrite (Plate 1i &

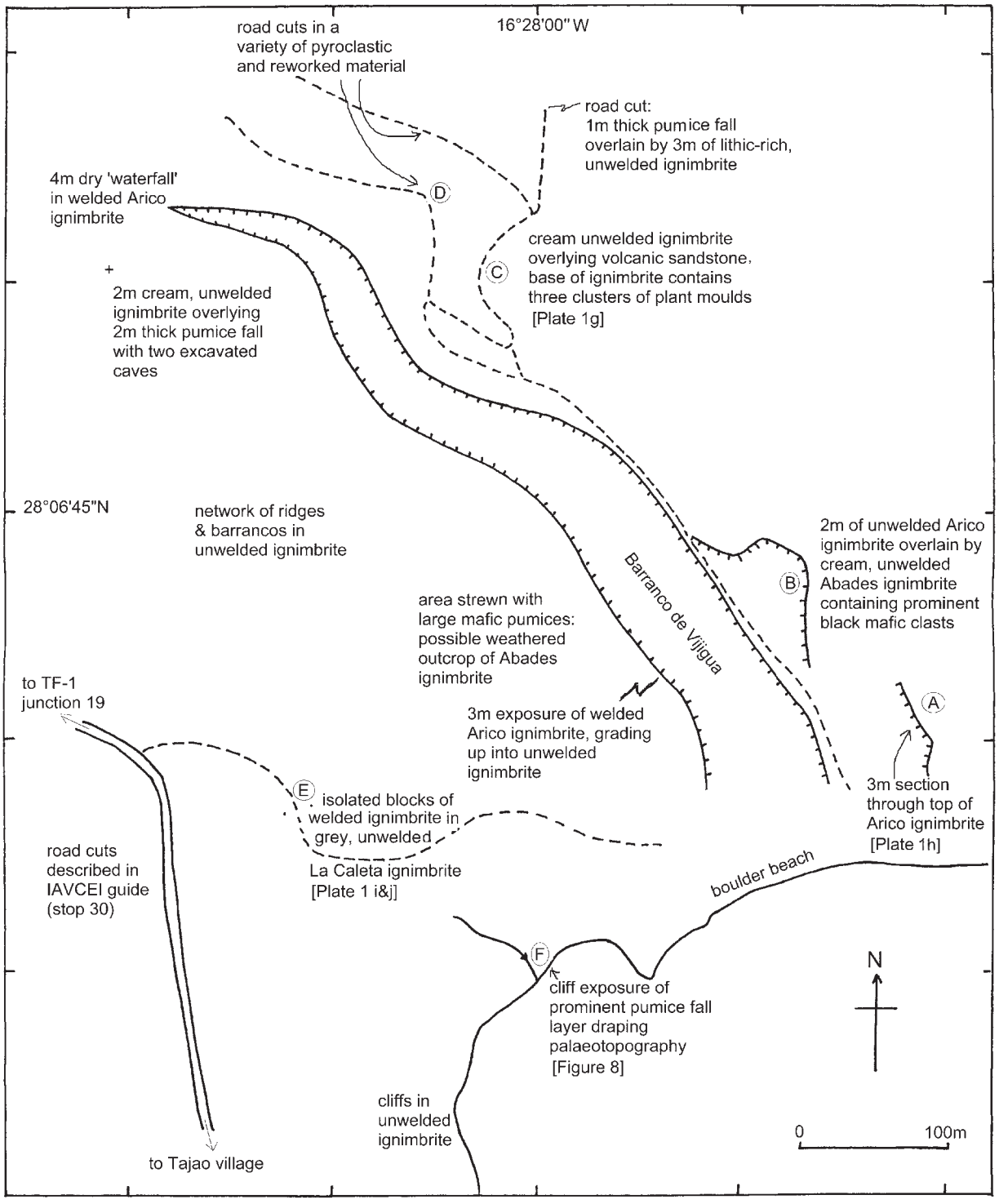
road cuts in a variety of pyroclastic and reworked material
16°28'00" W
road cut: 1m thick pumice fall overlain by 3m of lithic-rich, unwelded ignimbrite
4m dry 'waterfall' in welded Arico ignimbrite
D
cream unwelded ignimbrite overlying volcanic sandstone, base of ignimbrite contains three clusters of plant moulds [Plate 1g]
C
2m cream, unwelded ignimbrite overlying 2m thick pumice fall with two excavated caves
28°06'45"N
network of ridges & barrancos in unwelded ignimbrite
2m of unwelded Arico ignimbrite overlain by cream, unwelded Abades ignimbrite containing prominent black mafic clasts
B
Barranco de Vijigua
area strewn with large mafic pumices: possible weathered outcrop of Abades ignimbrite
to TF-1 junction 19
3m exposure of welded Arico ignimbrite, grading up into unwelded ignimbrite
A
3m section through top of Arico ignimbrite [Plate 1h]
E
isolated blocks of welded ignimbrite in grey, unwelded La Caleta ignimbrite [Plate 1 i&j]
road cuts described in IAVCEI guide (stop 30)
boulder beach
F
cliff exposure of prominent pumice fall layer draping palaeotopography [Figure 8]
N
cliffs in unwelded ignimbrite
0
100m
to Tajao village

Figure 4. Edited field sheet for the Tajao area south of the Autopista (TF-1). Symbols as per Figure 2. Based on GPS survey of 6-7 February 2005. GPS datum: Pico de las Nieves.

j). The clast in Plate 1i is illustrated in Bryan *et al.* (1998 Figure 4B). They consider the welding of the ignimbrite to be of much higher grade than anything found locally in the Arico ignimbrite and suggest that the block has been detached from the caldera wall and transported a considerable distance by the pyroclastic flow.

The area contains a number of pumice fall deposits: these are generally much better sorted than ignimbrites, and comprise grain-supported pumice clasts with minor lithic clasts that are usually smaller than the adjacent pumices. Figure 8 shows a prominent fall unit around 0.5 m thick in a cliff exposure at Location F on Figure 4, where the fall deposit has mantled the underlying palaeotopography.

With the exception of the Arico ignimbrite, all ignimbrites in the Tajao area are unwelded. The extent of welding in ignimbrites is related to emplacement temperature, thickness of unit, volatile content (Sparks *et al.* 1999) and also chemical composition, with high alkali concentration favouring welding. The composition of the Arico ignimbrite is significantly more peralkaline than the other ignimbrite units (Gill & Thirlwall 2003). In this respect, the Arico ignimbite is similar to many of the welded ignimbrites of Gran Canaria (Woodcock 2005).

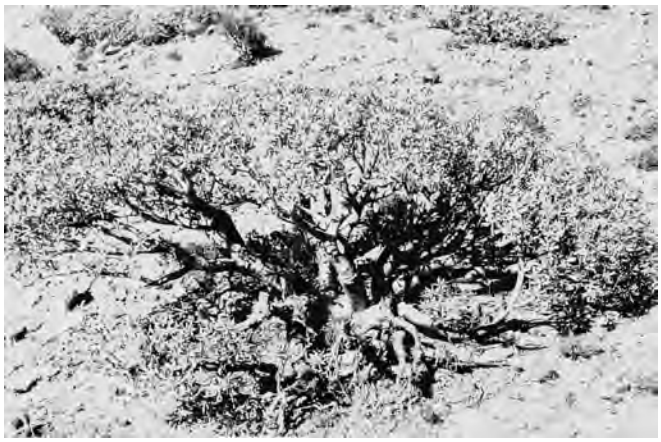

Figure 5. Modern shrub that may be similar to the one producing the moulds in Plate 1g.

Summary

A sequence of ignimbrites, together with subsidiary pyroclastic fall deposits and lava flows, is well exposed in the arid coastal area of SE Tenerife. The area around Tajao contains outstanding exposures within a small area, but does not seem to have been described previously in the literature. Despite its visual unattractiveness, the Bandas del Sur is an area of considerable geological interest.

Figure 6. Road cut at Location D, Figure 4. See Figure 7 for a schematic stratigraphic section of the exposure. Height of road cut c.5m.

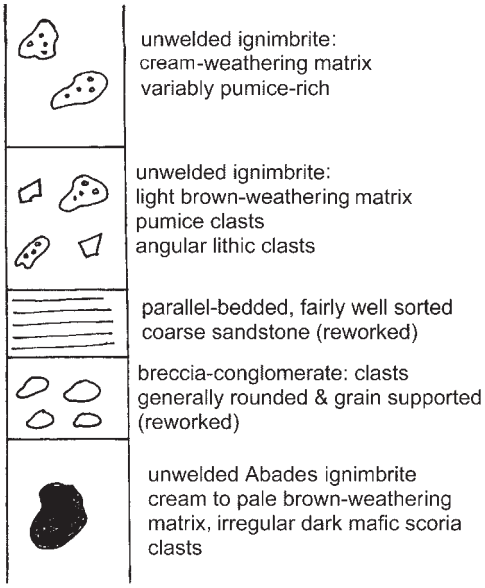

Figure 7. Schematic stratigraphic section of the exposure shown in Figure 6. Not to scale.

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Figure 8. Thin (0.5 m) pumice fall deposit draping a "palaeovalley" cut into the underlying ignimbrite and overlain by a younger ignimbrite unit. Location F, Figure 4.

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Field Observations in the Silesian rocks on the west coast of Carmarthen Bay

John Downes

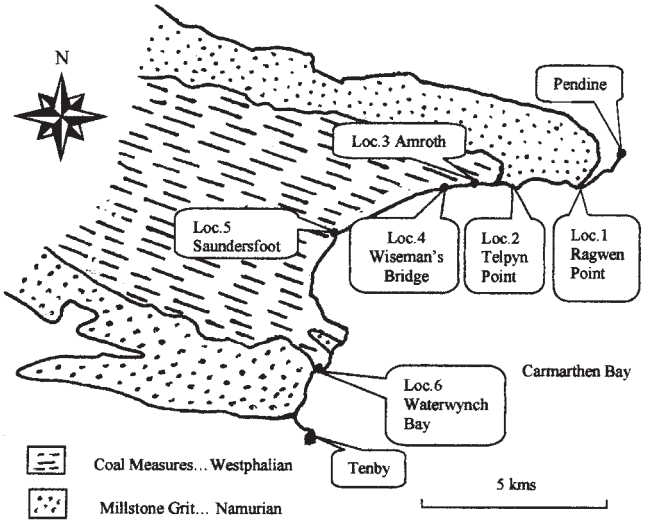


Figure 1. Silesian outcrops in Carmarthen Bay west.

The Silesian (Upper Carboniferous) rocks of the Pembrokeshire coalfield can be subdivided into Namurian (Millstone Grit) and Westphalian (Coal Measures). They form a compressed syncline trending WNW–ESE from St Brides Bay across to Carmarthen Bay (Figure 1) The southern limb of the syncline displays complex folding and faulting resulting from the Variscan earth movements. Namurian strata outcrop on the coast of Carmarthen Bay between Pendine and Amroth and immediately north of Tenby. These rocks can be subdivided into three groups: i).Basal Grits, ii) Middle Shales and iii) Upper Sandstone as shown on the stratigraphical column for the area (Figure 2). The Westphalian begins with the *Gastrioceras subcrenatum* marine band which outcrops to the east of Amroth and again to the south of Waterwynch Bay. Both Lower and Middle Coal Measures are exposed on the coast between these two locations where they comprise a series of mudstones, shales, lenticular sandstones and thin anthracite seams. The following localities display characteristic Silesian lithology and Variscan structures and are relatively easy to access providing the tidal conditions are suitable.

1.Ragwen Point (SN221071) is best approached by the track leading off the Amroth – Pendine road about 200m SE of Pendine church near to Great House Farm. Cars can be parked in the layby near to the farm. About 100m down the track bear left; then follow the bridleway down to the main cobbled track leading south to the bay between Gilman Point and Ragwen Point. The erosional contact between the underlying Carboniferous Limestone (Visean; *Dibunophyllum zone*) and the Basal Grit Group (Namurian; *Reticuloceras zone*) can be seen at the base of the cliffs on the east side of Ragwen Point. The limestones are interbedded with thin mudstones and display a rich brachiopod fauna with large burrows (*Thalassinoides*) occurring on some bedding planes. The sub-Namurian unconformity between the two lithologies marks a major environmental change from the shallow shelf seas in which the Visean carbonates were deposited to the fluvial and deltaic conditions that produced the Namurian shale/grit facies. Palaeocurrent studies suggest that the latter appear to have been derived from sediments brought down by

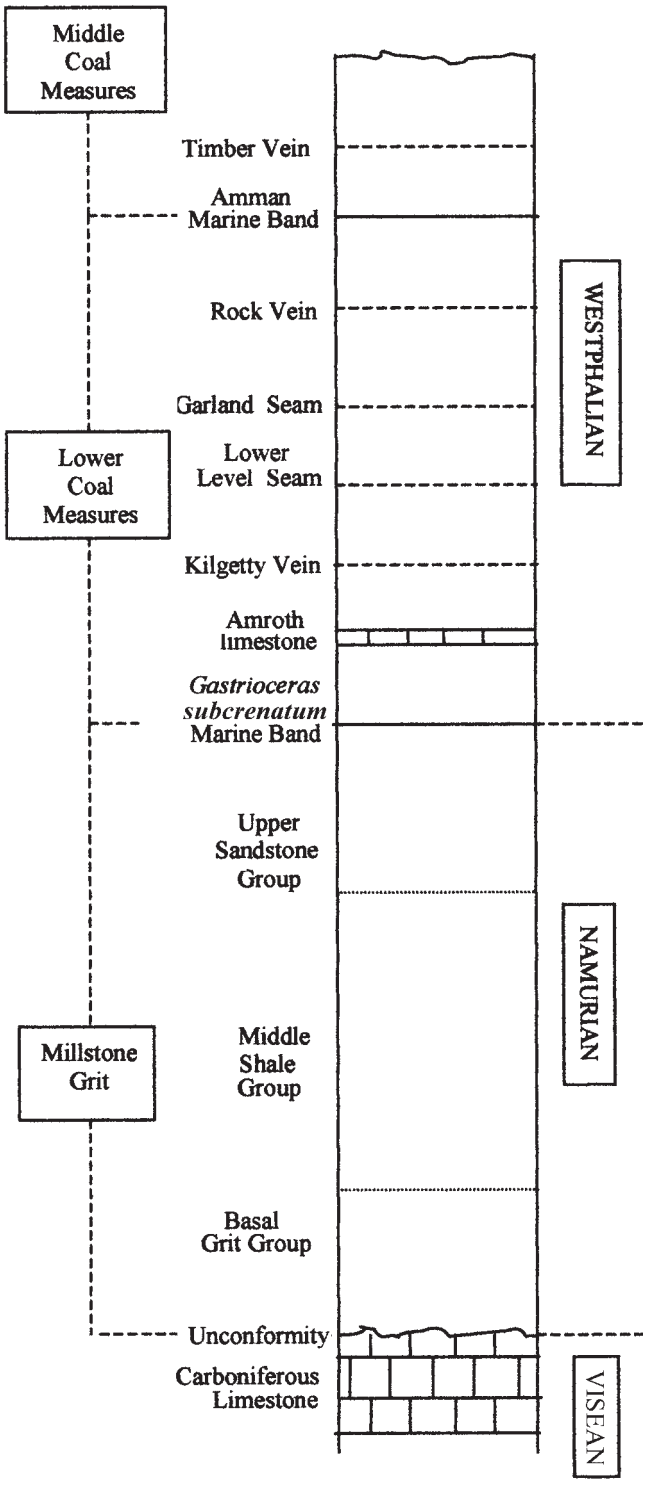
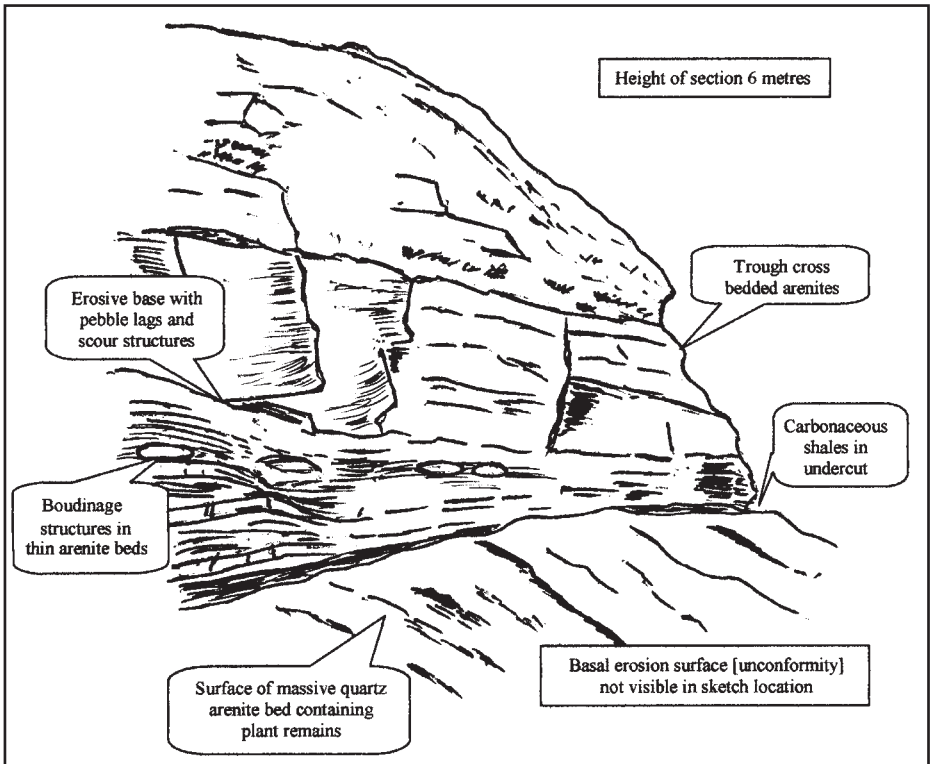


Figure 2. Stratigraphical column for the Silesian strata in Carmarthen Bay.


Height of section 6 metres
Trough cross bedded arenites
Erosive base with pebble lags and scour structures
Carbonaceous shales in undercut
Boudinage structures in thin arenite beds
Basal erosion surface [unconformity] not visible in sketch location
Surface of massive quartz arenite bed containing plant remains
Figure 3. Ragwen Point.

rivers flowing SW over uplifted ORS outcrops in the Brecon uplands. The following beds can be identified at the end of Ragwen Point:

i) Dark-coloured quartz arenites with trough cross-stratification and disseminated carbonaceous debris occur immediately above the basal erosion surface (unconformity). Plant remains such as club mosses and horsetails are common on the surface of the arenite bed (Figure 3). These arenaceous sediments have been interpreted as braided distributary channel deposits formed on a fan delta prograding into a shallow marine embayment.

ii) There is a distinctive undercut immediately above the arenite bed where carbonaceous mudstones and coal streaks have been eroded out by the sea. These represent suspension deposits laid down in swampy interchannel troughs on a delta plain.

iii) The overlying bed is a medium-grained quartz arenite with small-scale trough cross-bedding which is considered to be a crevasse splay deposit produced when rivers in spate cut through their levees and laid down lobes of sediment on the flood plain. Some of the more competent arenite beds have been stretched and folded to form boudinage structures.

iv) Finally there is a return to braided channel-fill deposits with thick arenites displaying trough cross-stratification. The sharp contact of the erosive base of this bed is undulating with pebble lags and scour structures.

2. Telpyn Point (SN186072) can be reached from the New Inn at Amroth. Vehicles can be parked alongside the road; then walk eastwards across the foreshore for 1km. The tide should be ebbing to ensure safe access. Alternatively at high tide, one can use the coast path that leads down from the Amroth to Pendine road through a narrow valley to a small inlet at SN183073. The Upper Sandstone Group (Namurian) is exposed from here to the eastern side of Telpyn Point. The inlet marks the location of a normal fault which downthrows the upper siltstones (to the east) against the underlying micaceous sandstones. Walk over the wave-cut platform to the face of Telpyn Point in order to examine the massive trough cross-bedded sandstones (channel fill deposits) that form the lower part of the Upper Sandstone Group. A prominent undulating erosional surface with lag deposits, marks the base of the sequence. However, above this base there are several other erosion surfaces marked by lag concentrates. Plant remains (*Calamites*), coal rafts, ironstone doggers and lenticular shales are present. Large flute casts can be seen on some erosion surfaces particularly where there are overhangs. Immediately below the basal erosion surface there is a thick sequence of siltstones (offshore distal turbidites) that belong to the upper part of the Middle Shale Group. These are best seen in the cliff on the east side of Telpyn Point (Figure 4) where several bands of sinusoidal ripples form a distinctive feature. Each line of ripples is in phase with those directly above and appears to have been deposited from suspension by a series of turbidite density currents.

3. Amroth (SN161070) is a seaside village on the north-eastern extremity of the Pembrokeshire Coalfield. The best exposures are seen in the cliffs immediately SW of the promenade where the Lower Coal Measures are strongly folded and cut by several thrust faults. Here the Kilgetty Vein coal, underlain by fireclay (seat earth), can be examined at beach level (Figure 5). It is overlain by a mudstone and thick cross-stratified sandstones. West of

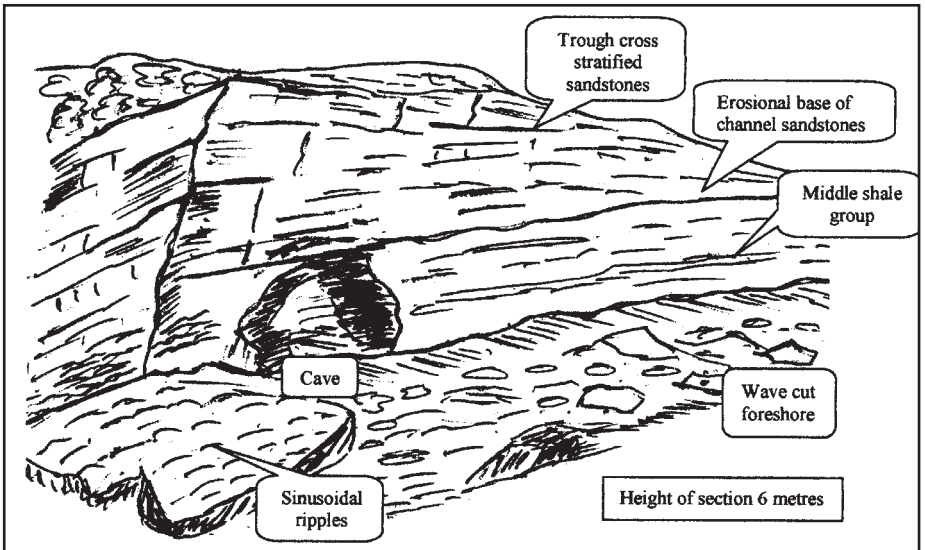


Figure 4 Telpyn Point - east side.

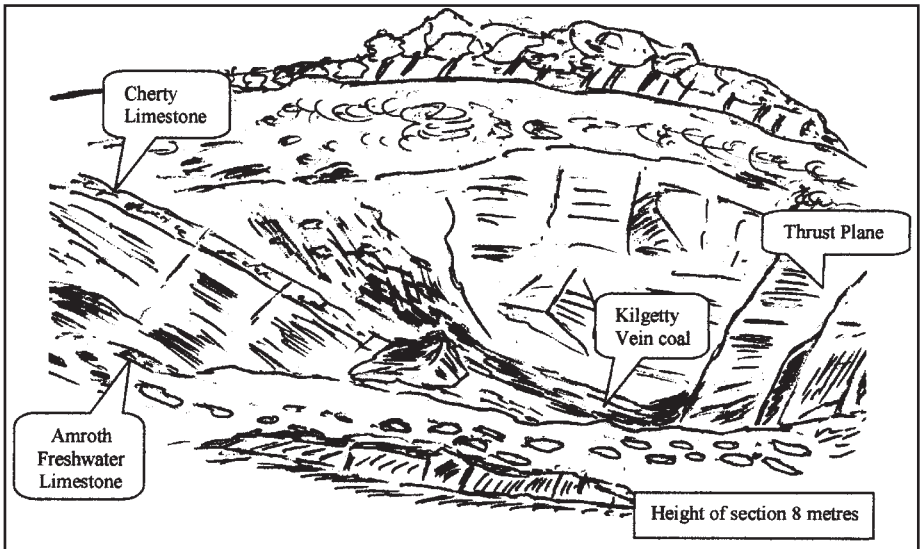


Figure 5. Amroth, south-west cliff.

this zone of disturbance there is a broad anticline (250m long) in which there are two distinctive marker horizons. First there is a light-coloured limestone with chert nodules that lies just below the Kilgetty Vein seam and can best be seen at the southern flank of the anticline. Secondly, about 6m below the cherty limestone is the distinctive Amroth Freshwater Limestone which is a red-brown-coloured bed about 1m thick and composed of the carbonate mineral ankerite. It contains abundant remains of the non-marine bivalve *Anthracosia regularis* and many small solution cavities where the shells have been weathered out.

There are repeated fining-up sequences (cyclothems) of sandstones, siltstones, seat earths, thin coal seams and mussel bands extending SW from the end of the anticline at SN157068. They represent a succession of floodplain deposits that accumulated in swamps and freshwater lakes in a coastal plain environment. These cyclothems can be examined either by continuing SW along the foreshore or by approaching from Wiseman's Bridge and walking NE towards Amroth, as described in the next locality.

4. Wiseman's Bridge (SN147062) is a small coastal settlement midway between Amroth and Saundersfoot. Park vehicles on the seafront near to the New Inn and walk to the cliffs alongside the public house. Here there are two high-angle faults in a V formation cutting the sandstone/siltstone sequence of the Middle Coal Measures which are gently dipping to the SW. Some 20m to the NE of the faults there are some excellent examples of contiguous minor distributary channels cross-cutting the sandstones/siltstones (Figure 6). The fill of each channel exhibits repeated fining-up units with a lag deposit at the base. The lag material includes small ironstone nodules and siltstone fragments in a sandy matrix.

The Timber Vein coal can be seen high in the cliffs but where there is a gap in the cliffs marked by a rock slide, a thin seam can be seen at beach level. Beyond this is a prominent sandstone reef (SN151064) with two seams of the Timber Vein Group well exposed in the centre of the reef. Abundant plant remains can be seen on the bedding plane below the lower coal seam. On the NE side of the reef there is a prominent sheared coal lying on a minor thrust plane.

The Amman Marine band outcrops in the next embayment where it is partially obscured by a rock slide. It marks the division between the Middle and Lower Coal Measures and forms a 30cm thick mudstone layer rich in brachiopods and goniatites. It represents a period of marine transgression when the sea inundated the coastal plain.

The next small headland (SN153065) marks the outcrop of the Rock Vein seam capping a series of channelled siltstones with large ironstone nodules.

Continue along the beach to the next reef where the Garland seam can be identified at the base of the cliff immediately SW of the thrust plane which cuts through the reef (SN155067). There are numerous deformation features in the cliff face including slumps and pseudonodules where rounded clasts have fallen into the underlying mud.

Beyond the thrust zone are the remains of an old mine building on the top of the cliff. The Lower Level seam outcrops here; note also the large fallen blocks of siltstone with symmetrical ripple marks on their upper surfaces. These ripples would have formed in a shallow lacrustrine environment where there was no tidal influence. The cliffs here also contain large septarian nodules and several thin coal seams. The next embayment is marked by another cliff slide beyond which is the southern flank of the broad anticline described in Locality 3

5. Saundersfoot (SN138047) is a small seaside resort about 5km north of Tenby. The cliffs to the south of the town expose the Lower Coal Measures (*communis* zone), which have been strongly folded by powerful Variscan earth movements. The rock wall forming the south side of the harbour is the almost vertical northern limb of an asymmetric anticline with its gently dipping southern limb reaching down to beach level. Beyond this there are several examples in the cliffs of overfolds cut by low angle thrust faults where thin coals including the Stammers Vein have been crushed between the underlying fireclay and massive sandstones above. These anthracitic coals have been subjected to considerable heat and pressure during orogenesis and are now referred to as 'culm'. However, one of the most spectacular structures is the Ladies' Anticline (Figure 7) which is about 500m south of the harbour. The strata here have been steeply folded asymmetrically but the structure is much eroded on the seaward side. This anticline is

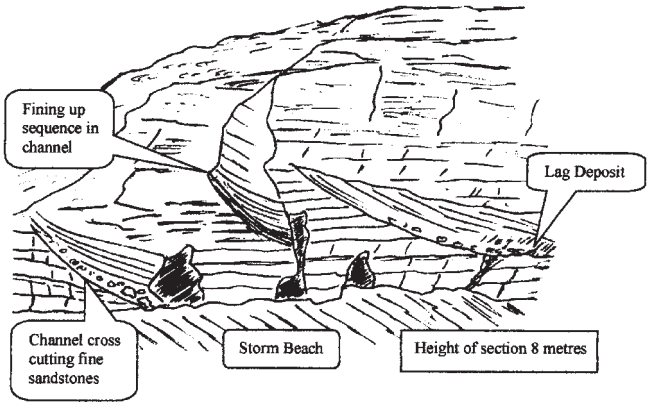


Figure 6. Cross-cutting channels in Middle Coal Measures near Wiseman's Bridge.

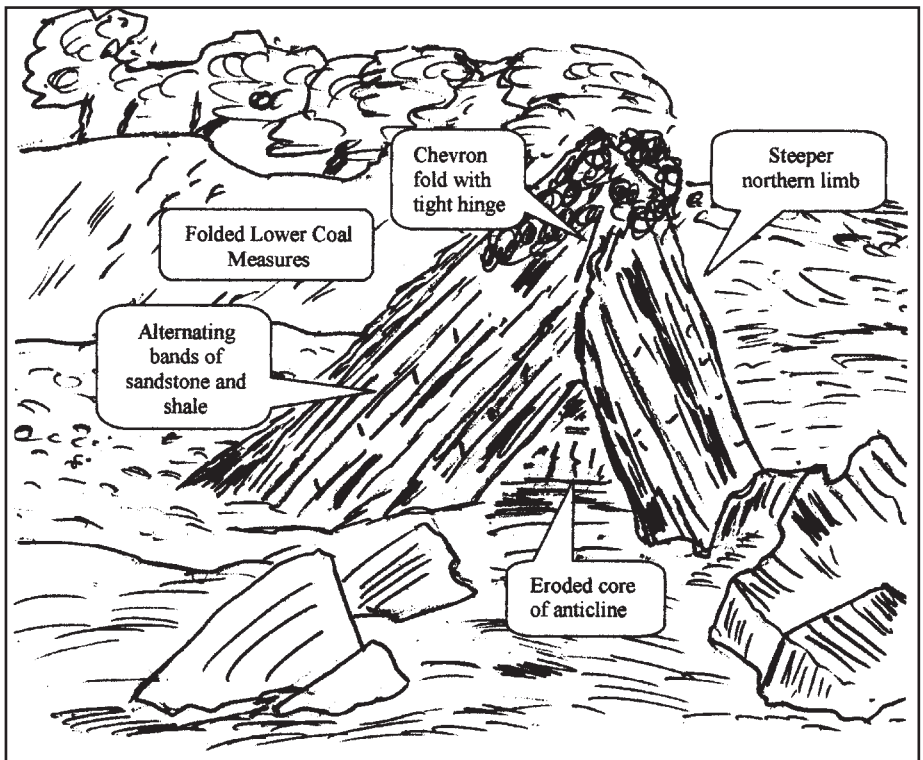

Chevron fold with tight hinge
Steeper northern limb
Folded Lower Coal Measures
Alternating bands of sandstone and shale
Eroded core of anticline

Figure 7. The Ladies' Anticline, Saundersfoot.

an example of a chevron fold where the long straight limbs are joined by a narrow hinge line. The more competent sandstone bands stand out prominently whilst the softer incompetent shales are worn back. The fold axis runs approximately in a E-W direction which is perpendicular to the direction of pressure of the Variscan orogeny. About 100m south of the Ladies' Anticline there is a major overfold in the massively bedded sandstone. This is channel fill sediment showing a strong erosional contact with the underlying shales. There are ripple markings on the underside of the sandstone and evidence of lag gravels. Some of the shales are fossiliferous containing freshwater bivalves (small dark mussels) belonging to the lowest zone of the Coal Measures (*Anthraconaia lenisulcata*). The large red-brown concretions on the foreshore are clay ironstones. These were in great demand in the early 19th century when iron smelting on the South Wales coalfield relied on local sources of Coal Measure iron ores.

Continue along the beach southwards towards Monkstone Point which is formed of a massive sandstone within the Lower Coal Measures. The headland follows the axial trend of a tightly folded anticline which can be observed at the eastern extremity of the point.

6. Waterwynch Bay (SN137020) can be accessed by the signposted lane leading off the A478 about 2km north of Tenby. Vehicles should be parked alongside the main road just south of the village of New Hedges; then walk down the private road to the beach. This is a public right of way leading to a footpath accessing the beach. Alternatively one can walk along the coastal path from Tenby (1km) and enjoy the fine views over Carmarthen Bay. However it must be stressed that this section along the foreshore from Waterwynch to North Beach, Tenby, can only be safely negotiated at low tide when the tidal height is 1m or less. Allow 2-3 hours in which to examine the rocks in safety.

Waterwynch Bay lies wholly within the Lower Coal Measures and the cliffs on the north side of the bay demonstrate deformational structures in a silt /mudstone sequence (Figure 8). Rheological features include slump sheets and rafts of sediment that must have moved down a depositional slope (delta front?) under the influence of gravity. The chaotic jumble of rocks within these structures suggests a rapid mobilisation of the material which was later engulfed in muddy sediment. Walk across the beach and negotiate the southern headland noting the bedded Lower Coal Measures sandstones dipping south at about 50°. Enter North Cove near the large rock slide which has occurred down a major bedding plane in the sandstones. Immediately to the south of this feature the ribs of several siltstone bands can be picked out on the beach striking E-W. These bands dip steeply south in the cliff face and pass into dark coloured shales containing the *Gastrioceras subcrenatum* marine band (marking a major marine transgression). A few metres to the south there is a distinctive thin coal seam, thrusted and contorted but containing abundant plant remains. This seam must lie near the top of the Upper Sandstone Group since the *subcrenatum* band marks the division between the Coal Measures and the Namurian (Figure 2).

The Upper Sandstone Group is composed largely of an alternating series of sandstones, siltstones and mudstones which have been interpreted as being inter-distributary bay deposits. However, several well-defined distributary channel sandstone beds are exposed in the sea cave at SN137018. These sandstones show extensive ripple marking and can be shown to be inverted. (i.e. the ripples were originally formed on the horizontal top surface of the bed which was subsequently rotated through about 100^0 by the Variscan earth movements). They form the northern limb of a major overturned anticlinal structure, the southern limb of which outcrops on the north side of First Point (Figure 9). About 20m south of the sea cave, there is a turbidite sequence in Bowman's Cove where flute casts can be seen on the surface of one of the thicker graded units (greywacke). It has been suggested that these beds represent the proximal deposits of a turbidite fan on the slopes of the delta front. Several good exposures of incomplete Bouma units can be identified; coarse grained turbidites with flute marks at the base, grade up into cross-stratified fine sandstones and siltstones with climbing ripples (Bouma units A, B &C).

At Bowman's Point there are some spectacular chevron folds in a faulted crumple zone on the NE face; however most of the headland is composed of southward-dipping ripple-laminated siltstones and fine sandstones which extend into Second Bay. Here the core of the main anticline is formed of mudstones (*Anthracoceras* marine band) of the Middle Shale Group. These are overlain by a coarsening-upward sequence of silty mudstones and sandstones representing delta slope deposits. At Second Point, siltstones with U-tube burrows and ripple laminations can be seen which appear to be stratigraphically equivalent to those at Bowman's Point. Walk across First Bay to examine the sandstones which form strong ribs cutting across the beach. These represent several channel deposits with strong erosional surfaces at the base of each cross-stratified bed. These are separated by thin interchannel siltstones.

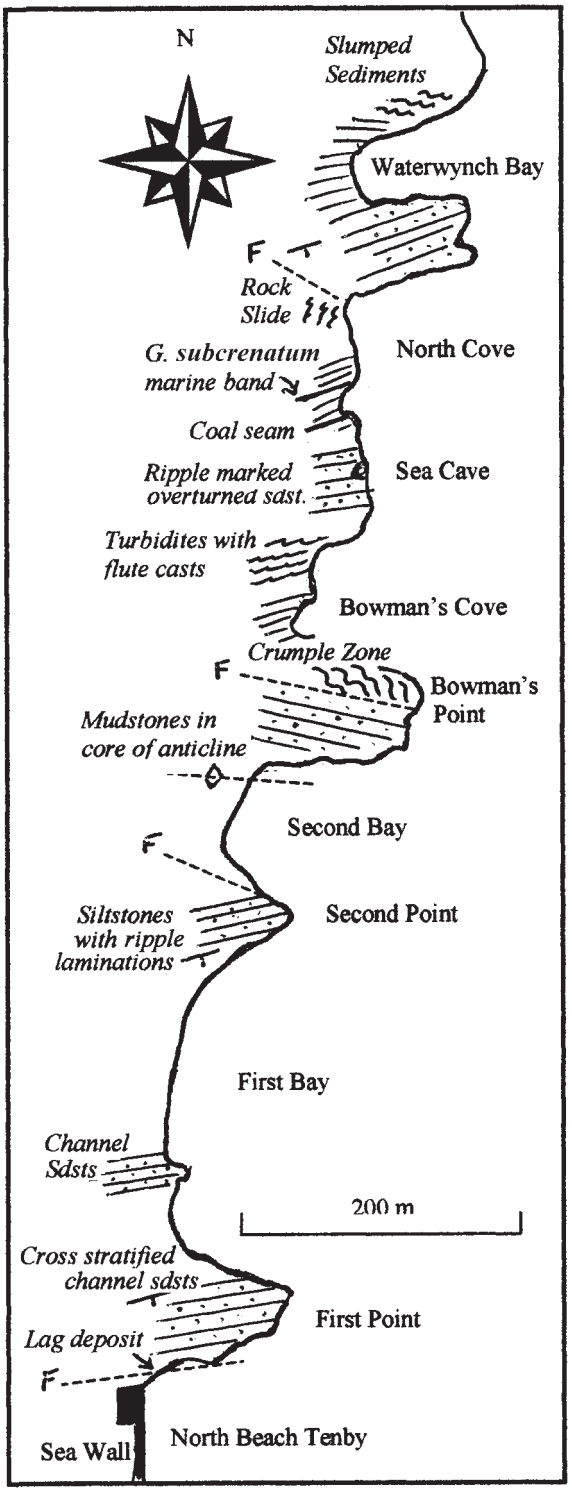


Figure 8. Sketch map of the geology of the coast from First Point to Waterwynch Bay.

At First Point (south side) the channel sandstone of the Upper Sandstone Group forms a complementary tight overturned syncline alongside a strong high-angle thrust fault near to the sea wall. The vertical cliff against the sea wall shows a distinctive channel lag deposit made up of well-rounded ironstone pebbles and mudstone clasts. On the north side of the headland there are well-developed tabular cross-stratified channel sandstones. The individual beds are about 1m thick with well-defined erosional planes dipping 40°S. These sandstones represent the deposits of a fluvial distributary system at the mouth of a delta.

Note that the main direction of thrusting is from the south with the fold vergence towards the north. Here we are on the southern limb of the Pembrokeshire coalfield where the Namurian strata have been overthrust northwards; and as a result, the overall synclinal structure of the coalfield is difficult to recognise in this area where folding and thrusting have considerably compressed the strata. By contrast on the northern limb of the syncline, the gently dipping Namurian passes conformably into the Coal Measures to the east of Amroth. Overall tectonic deformation along the southern margin of the coalfield has reduced its width to only one third of that of its counterpart in the main South Wales basin.

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Maps: Geological Survey 1:50,000 Sheet 228 Haverfordwest

Geological Survey 1:50,000 Sheet 229 Carmarthen

Ordnance Survey 1:50,000 Outdoor Leisure Sheet 36 South Pembrokeshire

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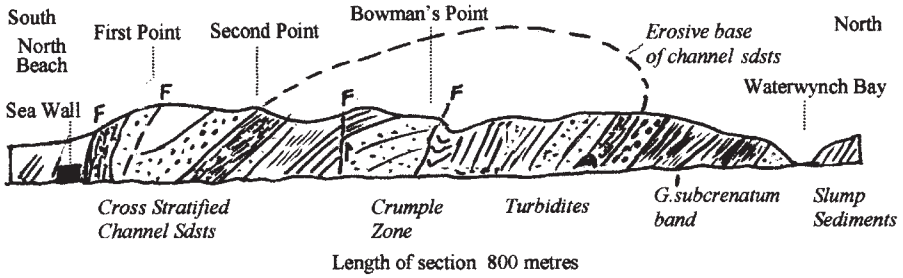

Fiure 9. Section from First Point to Waterwynch Bay.

The Palaeolithic in Britain

Gladys Dinnacombe

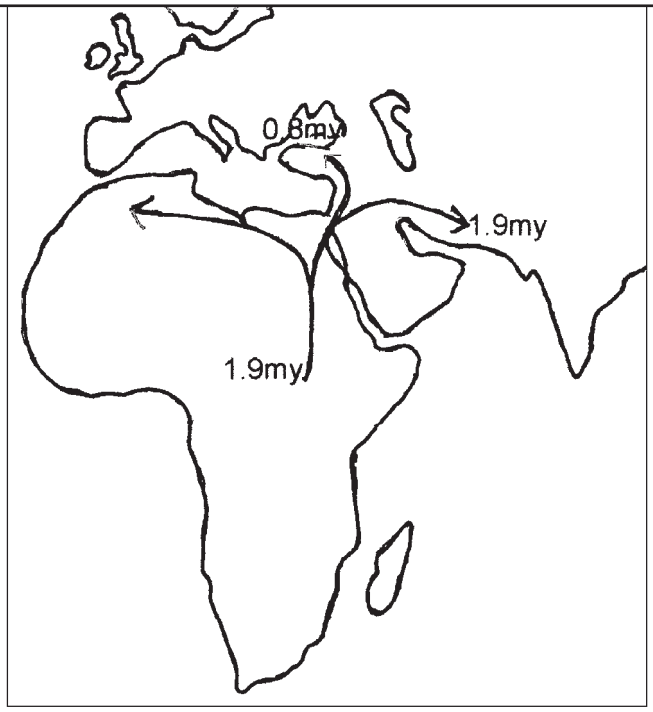

Figure 1. Sketch map to show routes into Europe (adapted from Barton 1997).

The Palaeolithic stretches from 10,000 BP back to 500,000 BP. BP stands for Before Present which is stated as 1950. The Palaeolithic itself is divided into three parts, Lower, Middle and Upper: each one representing in some way, a change in culture or tools (Table 1). The first humans in the world stem from Africa in 2,500,000 BP. Figure 1 shows how they spread to Europe and other parts of the world.

In order to consider the way the early humans lived, we need to look at the Ice Age and the way it affected our climate. The Ice Age consisted of cycles of intensive cold when the ice sheets expanded. These occurred during the Pleistocene which lasted about 1.8 million years and ended about 10,000 BP; followed by the Holocene epoch. There were approximately nine major advances of ice across Europe and the US. The coldest periods were known as glacials and the warmer episodes as interglacials. Smaller episodes of warming were called interstadials while smaller episodes of cooling were known as stadials.

In Britain, the glacials brought an arctic environment while the interglacials were often warmer than today! Currently we are in a long warm interglacial which began between 14-13,000 BP. Evidence of previous environments can be obtained from deep-sea cores, ice cores and long pollen sequences.

The cold stages were given names and those we need to know for the purpose of this article are the Loch Lomond, the Devensian and the Anglian cold stages. The extent of these can be seen on Figure 2.

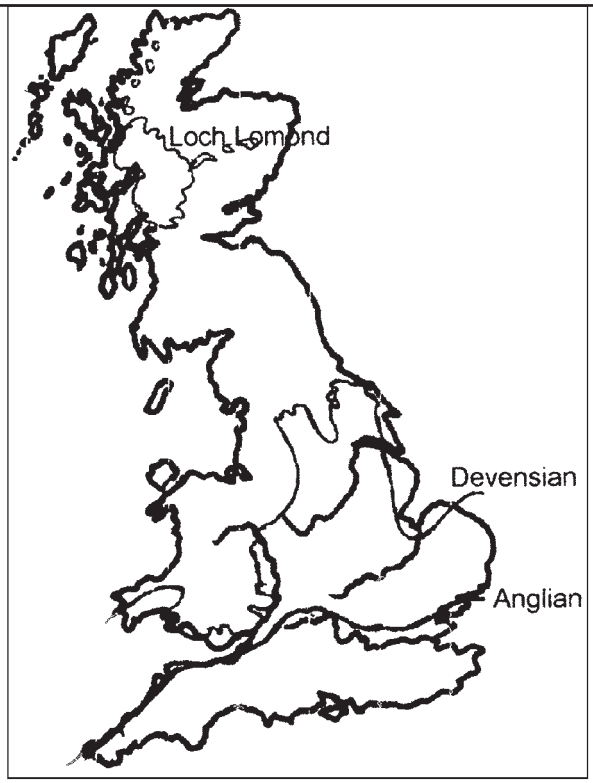

Figure 2. Maximum ice advances for the Loch Lomond, Anglian and Devensian cold stages (adapted from Barton 1997).

Table 1. Division of the Palaeolithic.

10000 BP	Late Upper Palaeolithic	Ice Age ends	First pottery in Japan
13000 BP	Early Upper Palaeolithic	Red Lady - Paviland Cave blade - based tools	Very cold. N. Europe abandoned, Cro-Magnon man; transition between Neanderthals and modern man
40000 BP	Middle Palaeolithic	Mousterian culture, flat based hand - axes	Neanderthals
130000 BP 500000 BP	Lower Palaeolithic	First humans in Britain Boxgrove hand - axes	
2500 000 BP			First humans, Africa

BP = Before Present = before 1950

Figure 3. Early fossil hominid sites and archaeological sites. 1) Boxgrove; 2) Kent's Cavern; 3) Westbury-sub-Mendip; 4) High Lodge; 5) Barnham; 6) Swanscombe.

The earliest evidence of human occupation in Britain has been found at Westbury-sub-Mendip; Kent's Cavern, Devon; High Lodge, Suffolk; Boxgrove, Sussex and in a few other areas. Artefacts were recovered in Cromerian deposits; a series of warm stages preceding the Anglian glaciation 524,000-478,000 BP (Figure 3); however, the first two sites mentioned above are caverns.

The Westbury-sub-Mendip site is a collapsed cavern in a Carboniferous limestone quarry which was investigated in 1976-1982. The cave sediments are sands, silts and clays (Figure 4). They contain abundant bones of extinct mammals, small vertebrates and birds. Also found were artefacts of coarse Greensand Chert; including flakes of a non-Acheulian industry in the

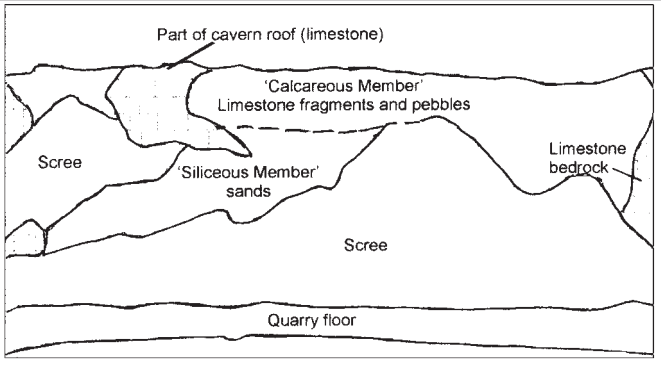

Figure 4. Sketch map of the geology of Westbury-sub-Mendip (after Stuart 1988)

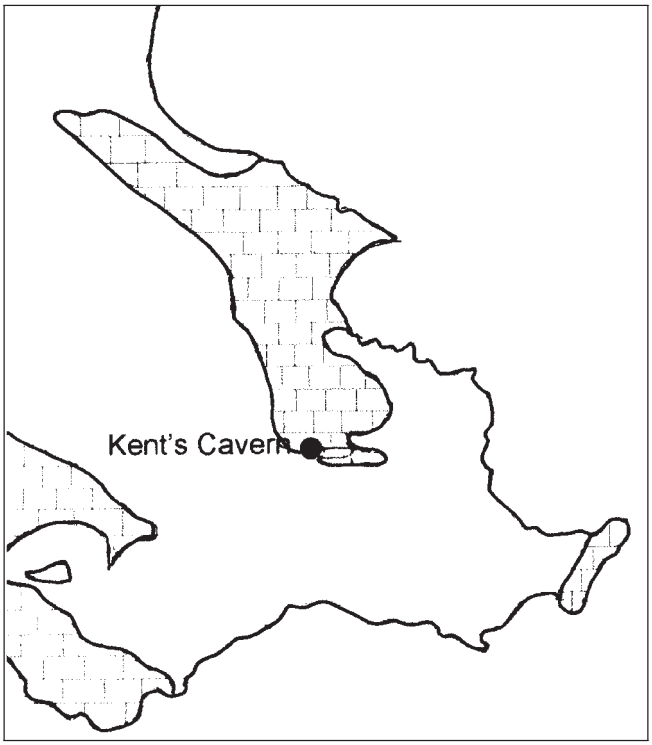

Figure 5. Sketch map of the geology around Kent's Cavern.

Calcareous Member of the sediments. These cavern-infill sediments were exposed by limestone quarrying in the late 1960's. A cut-marked bone was also found in the main chamber. The site is dated to the middle of the Cromerian.

Kent's Cavern, Devon, is open to the public but it was explored from 1820 onwards. Acheulian hand-axes were found which were dated to pre-Anglian or early Anglian ages. The cave itself is in the Devonian limestone (Figure 5), massive beds formed when reefs developed in clear shallow water, but the artefacts were found in a breccia, dispersed both horizontally and vertically which indicates a possible derivation from sources outside the cave. The breccia is a poorly sorted, allochthonous deposit consisting of Devonian sandstone, siltstone, slate and vein quartz cobbles and pebbles in a dense clayey matrix. The artefacts were hand-axes made in different ways, some of them using a trihedral reduction style. The flint source is possibly an accumulation of supracretaceous flint-gravel which occurs about four miles from the cave. Table 2 shows the modes of hand-axe production. Modes 1 and 2 are possibly contemporary, the tools being made for different functions or by different groups of people with different stone-working traditions.

The site at High Lodge, Suffolk was excavated in 1962-8 and 1988. High Lodge is situated in a region composed of Cretaceous bedrock and overlain by Quaternary sediments. Clayey silts represent fine-grained floodplain deposits of the Bytham River formed during a pre-Anglian temperate phase.

The Bytham River was a major river system flowing from the Midlands to north-west Norfolk, then south and east across Norfolk and Suffolk (Figure 6). The Bytham sands and gravels are a characteristic suite of quartz and quartzite-rich sands and gravels deposited prior to the Anglian glaciation by the River Bytham. The sediments contain abundant quartzose material derived from the Triassic pebble beds of the Midlands plus locally derived flint.

Table 2. Modes of manufacture of stone tools.

Period	Mode	Stone tools
Lower Palaeolithic	Mode 1	Flakes struck from cores by hard hammers. Some flakes retouched as tools with hard hammers.
	Mode 2	Hand-axes made with hard or soft hammers, flaked round the majority of the perimeter, to create a working-edge. Retouched flake tools.
Middle Palaeolithic	Mode 3	Levallois flakes from prepared discoidal or prismatic cores. Retouched flake tools.
Upper Palaeolithic	Mode 4	Composite tools from narrow blades in many different forms.

The Bytham River was the major river of the whole of the Midlands by Cromerian times and its deposits immediately underlie those of the Wolstonian sequence. In the Waverly Wood area of Warwickshire, along the course of the Bytham River, pre-Anglian organic deposits and artefacts have been found below the main body of river sediments. In Leicestershire, the river followed roughly the valley of the present River Soar. The Anglian sequence is mainly chalky Lowestoft till and glaciofluvial sands and gravels and fine-grained deposits. In East Anglia there is evidence for the long duration of the Bytham River which survives in the form of different river terrace levels from at least four different glacial stages, the last of which is the pre-Anglian. Tributaries of the Bytham River brought an influx of materials from the Bunter Pebble Beds, Carboniferous material and chert. Artefacts of non-Acheulian mode were found. These were finely made side scrapers and 'flaked' flakes and were dated to pre-Anglian. The artefacts show that the area was fully exploited by humans.

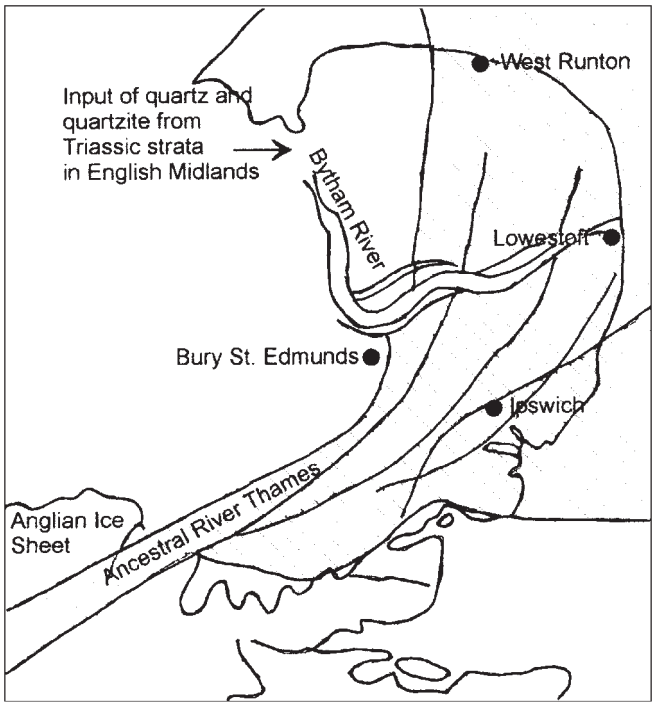

Figure 6. Sketch map of the geology of the Lark Valley Suffolk.

The Warren Hill site is immediately downstream of High Lodge. Here there is a basal unit of fine sand with bimodal cross-bedding, which indicates a moderate-energy tidal-current deposit, of the Wroxham Crag Formation. This is the easternmost extent of the Crag sea in this area. The upper lithological unit is 10m thick and is a cross-bedded sand and gravel, indicative of a braided-river environment. The clast content indicates transport from regions with Triassic, Carboniferous and Jurassic bedrock such as those in the Midlands. There are also some large chalk cobbles and boulders. These sediments are part of the Bytham River deposits and are attributed to the second terrace of the Bytham Sands and Gravels. This terrace is now known as the Warren Hill Terrace (Rose 1992). Artefacts found here include bifaces and flakes which predate the Anglian of the Pleistocene. Human occupation has been dated to around 550,000 years BP.

Pleistocene deposits form four distinct groups in the Sussex-Hampshire coastal areas:

1) marine gravels, sands and silts formed during interglacial temperate stages and fine-grained sediments capping the marine sequences associated with sea-level regression phases
2) coarse, poorly sorted angular flint gravels and silts associated with periglacial, cold climate stages. These overlie the interglacial marine deposits
3) flint gravels deposited by fluvial action in valleys such as the Solent and the Arun
4) sediments preserved in abandoned or buried channels like those between Selsey and West Wittering (Whitaker *et al*. 2004).

The Pleistocene deposits overlie either the Cretaceous Chalk or Tertiary clays and silts. Deposits containing Palaeolithic archaeological material consist of a 'staircase' of marine and terrestrial deposits with the highest-altitude deposits being of the oldest age (Slindon-Goodwood raised beach). Younger sets of deposits occur at lower altitudes across the coastal plain towards the present coastline. In the eastern Solent basin the marine/terrestrial deposits are restricted and replaced by fluvial sediments laid down in the former Solent River.

At the current time, the oldest human remains in Britain have been found in Boxgrove. They were discovered during commercial quarrying (Figure 7). The remains found were a shin bone

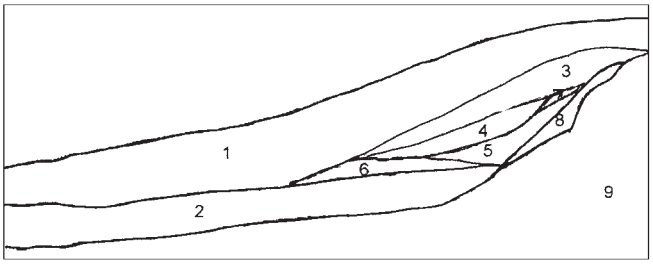

Figure 7. Sketch of the section at Boxgrove.
1) Solifluction gravels (decalcified)
2) Slindon Sands
3) Solifluction gravels (chalky)
4) Path gravels
5) Chalk pellets
6) Brick earth
7) Cliff collapse
8) Raised beach
9) Chalk

from a left leg and two human front teeth. Information gained from the shin bone/tibia was that the human was about six feet tall, weighed around twelve and a half stone, was most likely male and was fairly muscular.

The tibia was very robust, thicker than ours and so indicates a physically demanding life. Scratches on the teeth indicated the cutting of meat close to the mouth, the scratches being identical to those found on animal bones. It is unlikely that these humans had speech but they would have been able to communicate in some way.

Tools found at Boxgrove were many, the majority being bifacially flaked hand-axes in various shapes; ovate and pointed. The hand-axes were around 80-150mm long, flaked on both faces and knapped to maximise their cutting qualities and to minimise their overall thickness. Waste flakes can be used to work out how the tools were made. Hammers were made of antler and also other bones. Bones of horse, rhino and deer were found, indicating that these animals were killed for food. Incisions in the bones indicate how the animal was skinned, jointed, boned and defleshed. Some bones had been smashed to obtain the marrow. The bones also indicate how the animal was hunted, possibly being killed by a wooden spear. Spears have been found in other areas and these were around six and a half feet long, some pointed at both ends.

The environment at the time of the human activity was in OIS 13 when sea levels were high and beat against the cliffs so that a storm beach formed at the base of the cliff and it is in these beach gravels that the ovate hand-axes were found. The beach continued out to sea for about 50m and then became part of the Slindon Sands which is a prolific source of hand-axes. As the seas retreated, a series of lagoons formed and in the lagoon sediments have been found a series of flint-knapping and butchery sites. The Boxgrove type section is as follows:

Marine deposits grade into finely laminated silts (deposited in lagoonal/tidal flat conditions)

Slindon Formation terminates with the development of fen carr deposits (thin brown line of mineralised organics)

Beds of silty brickearth and soliflucted gravels (Eartham Formation),

Gravels deposited by mass movement and solifluction flows when the permafrost thawed.

The flint-knapping site contained an entire scatter which was recovered and refitted to show how hand-axes were manufactured. At the horse butchery site, cut marks on the bones indicated how the butchery process was worked out. The limb bones had been fractured so that the marrow could be obtained. After the hunters left, the scavengers moved in which is proven by gnaw marks which overlay cut marks. There were a series of knapping episodes around the carcass which indicated that rough-outs had been made in one place and the axes finished in another one. Lumps of flint with one battered side were probably used as anvils while beach pebbles were used as hammerstones.

The sea level continued to fall and the lagoons dried out, soil forming over them. It is assumed that this then became a grassy plain with bushes and scrubland grazed by such animals as red deer, rhinos, giant deer and horses. Flint nodules from the chalk had been tried out as axes but many had been rejected.

The site would have been close to the sea at that time, 524,000-476,000 BP. This date was arrived at by using voles and their evolution as dating markers. This was supported by other fossil evidence of mammals. This date belongs to an interglacial at the end of the Cromerian and is therefore pre-Anglian.

Another recent site is at Barnham. This site was excavated before road building began and a small buried valley was found crossing a hill that 300,000 years ago had been a tributary of the Avon River. Evidence shows that this period was a warm interglacial during a glacially cold time. The deposits lining the valley consist of a chalk bedrock, overlain by coarse gravel, in turn overlain by 70cm of fine sand or silt. Along the west side of the valley the sand is covered with chalk rubble which apparently represents a slumped valley side. Flint artefacts were found in the gravel, sand and the slumped chalk. The gravel is likely to have been laid down in the river in a cool or cold climate. The artefacts are typical of the Lower Palaeolithic and have been dated to 250,000 BP.

Wallingford Fan Gravels have also produced archaeological artefacts. The gravels lie in a strip about 11km long and up to 6km wide on the Lower and Middle Chalk plateau at the foot of the southern Chilterns. The gravel thickness is up to 7.5m locally. The Angular Flint Gravel is a subdivision of the Plateau Gravel and consists of angular flint in a matrix of quartz sand or loam derived from the Reading Beds (Arkell 1943/44). Hand-axes were found here and are largely derived from the Clay-with-Flints deposit which is a solifluction product of earlier glaciations.

During the Anglian cold stage, there is no evidence of humans but the Hoxnian interglacial of 303-339,000 BP contains abundant artefacts.

At Hoxne in Suffolk, a large hollow in boulder clay filled with water, forming a lake which provides a good pollen record for the time. In the sands, silts and gravels overlying the ancient lake deposits hand-axes of the Acheulian type were found together with flakes. At Clacton-on-Sea, flint tools, cores and flakes were found. These were obtained from deposits laid down by the ancestral river Thames (Figure 8).

The name Neanderthals comes from the Neander Valley in Germany where human bones and part of a skull were discovered in 1856. Neanderthals were found over Europe and western Asia (not Africa). Fossil evidence for the Neanderthals dates from 130,000 to 30,000 years ago. The majority of bones have been discovered in caves. The differences between the Neanderthals and modern man are as follows;

The Neanderthals have:

- low-swept forehead
- thick brow ridges

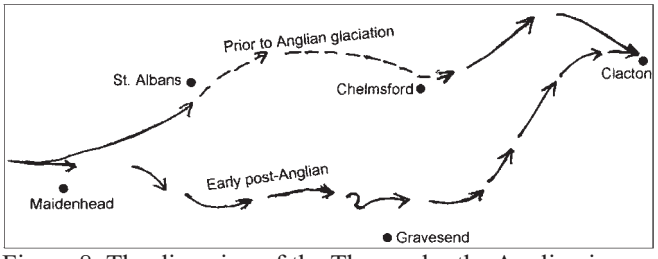

Figure 8. The diversion of the Thames by the Anglian ice sheet (adapted from Bridgland 1994).

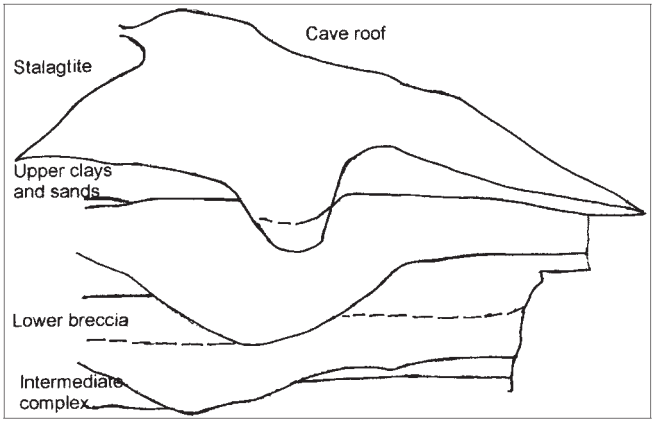

Figure 9. Sketch map of the geology of Pontnewydd Cave.

- projecting face with broad nose
- massive barrel-shaped chests
- stout bones and powerful muscles
- forearms and lower legs shorter in relation to upper parts of limbs
- stocky, thick-set - adapted to cold
- front teeth large and shovel shaped.

They were able to communicate verbally. There is no fossil evidence for the Neanderthals in Britain but artefacts and occupational debris in caves and open locations indicate Neanderthal activity in southern and midland Britain in the last glaciation. No burials were found in Britain but in Europe burials showed they were buried lying on their side or with one hand drawn up to the face. Grave goods included stone tools, ochre fragments and animal parts and the body was often covered by stone cairns.

The Neanderthals had sophisticated tool-making skills, a complex social organization, were the first Europeans to bury their dead, had a Middle Palaeolithic culture and their industries were grouped under Mousterian after the site Le Moustier in France.

The Mousterian industry was based on production of flakes, used as sharp cutting edges or modified into retouched tools. Flake tools had a restricted range; small triangular points, side scrapers, notches, saw-edge tools and thin, flat-based hand-axes. The Levallois technique was used, a method of making stone flakes of predetermined size and thickness. Wear patterns show tools used for hide scraping, woodworking (chopping and whittling) as well as butchery. Recent discoveries in Spain show that wooden platters were made.

British Mousterian sites include Pontnewydd Cave (Figure 9) where artefacts of the Levallois type and Acheulian hand-axes were found together with mammal remains and human teeth. This cave was inhabited about 210,000 years ago. In Kent, rock shelters formed by natural caves and overhangs in the sandstone crags produced artefacts of the Mousterian type. The caves occur in a soft sandy silty layer which is between a hard chert layer and a sandstone layer below.

A recent site has been exposed at Lynford Quarry near Thetford in Norfolk. This is becoming known as a Neanderthal butchery site because of the remains and artefacts found there. There are two deposits: an upper dark brown sandy organic layer with occasional streaks of lighter sand and occasional flints and a lower layer of sand and silt with some flint gravel. The sand fill has been dated to around 60-65,000 years old in the Middle Palaeolithic. Artefacts such as hand-axes and flakes were discovered as well as many animal bones. Some of the bones had cut marks and had been split to obtain the marrow. The hand-axes were of the sub-triangular or ovate type. The animal bones have enabled an understanding of the climate at this time. Several species such as mammoth and woolly rhino are associated with cold, dry grassland.

The period between 40,000 and 30,000 BP was a time of transition and the time of the earliest anatomically modern humans known as Cro-Magnon. They had flatter faces, larger teeth, bigger brains and were taller than today. The Neanderthals and early modern man lived side by side for about 10,000 years

During the Upper Palaeolithic, methods of working tools improved, there were new forms of stone tools and the first appearance of personal ornaments including decorated forms appeared. There were reliable storage methods, long-distance movement of flint and shells, new hunting techniques and highly elaborate burials.

The Upper Palaeolithic is divided into cultural sub-stages defined chronologically and on the basis of progressive developments in artefact forms as shown in Table 3.

There was a sharp increase in the production of narrow, parallel sided blades, increased reliance on hafted tools, it was easier to replace blades and glues date from the Middle Palaeolithic. The range of tools also increased, scrapers, borers, piercers, burins (chisel-ended implements). This implies better skills in working ivory, antler and bone. Spear throwers were made about 18,000 years ago and there is evidence of seasonal hunting.

Cro-Magnon man was buried lying flat and extended, often single, double or multiple graves, sometimes in pits out in the open as opposed to caves. Early Upper Palaeolithic burials were accompanied by special grave goods e.g. red ochre sprinkled as powder over the corpse, ornaments made of shells, ivory, teeth and fish vertebrae which were possibly sewn on clothing. The earliest date for statuettes is 33,000-30,000 BP in Germany. There were mammoth, bear and bison figures while Venus figurines date to 26,000 BP in the Gravettian culture.

There was movement of objects over long distances which indicates advances in social organisation. Shells, amber, flints, could be traded for food or other resources. Storage pits were used for meat in cold areas and we believe that meat was also smoked although there is no archaeological record of this. Hearths were

Table 3. Cultural sub-stages.

Aurignacian 43,000 BP	early Upper Palaeolithic preceding the coldest part of the last glaciation (18,000 BP)
Upper Perigordian (Gravettian)	
Solutrean	
Magdalenian 15,000 BP	late Upper Palaeolithic, ends about 10,000 years ago with onset of postglacial conditions
Hamburgian	
Creswellian	
Federmesser	
Ahrensburgian	

well built with stone borders and/or linings and evidence suggests socialising around the hearths. Oven-like hearths were used for baking clay. The development of language is indicated.

A recently excavated site of this age is at Glaston in Rutland. It has been dated to 40-30,000 so it is an Upper Palaeolithic site. The site is founded on soft Jurassic sands which are probably the bed of a marine lake. Overlying the sands are large sandstone rocks which are the eroded remains of a Lincolnshire Limestone layer. These sandstone blocks, rich in carbonates, have helped to preserve the bones at this site. The area would have been a high ridge when occupied. There are two parts to the site, one human and one a hyaena den. In the human part, a single leaf-shaped point was found which was possibly a spear tip. There was also a flint core and large waste flakes. In the hyaena part, there were remains of feasting, gnawed bones and fossilised droppings and also a burrow. Many small bones in the area could be from raptor pellets.

Other British sites include Ossoms Cave in the Manifold Valley, Derbyshire. This is an Upper Palaeolithic site where animal remains were found with flint artefacts. Ash deposits showed that fires had been lit. The site has been dated to 10,600-10,780 BP.

Gough's Cave, Cheddar, was excavated and artefacts and animal bones were found. Some artefacts were made of bone and antler and there were also beads made from fox teeth, bone piercers and evidence of needles being made from bone. Remains of three adults and two children were also found. The site has been dated to between 12,800-11,900 BP.

In Paviland Cave in South Wales, a skeleton was found buried with red ochre staining, together with ivory bracelets and rods (mammoth ivory) and small perforated periwinkle seashells. The skeleton was of a young male, 25 years of age, 1.7m tall (known as the Red Lady as he was originally thought to be female) and the age of the skeleton was 18,000 years which is within the last glacial maximum although a new date is of around 26,350 BP. Tools such as scrapers and burins were found and also artefacts of Gravettian age (28,000-22,000 BP). Ochre could be used in leather working and for colour decoration.

At end of the last Ice Age, the people retreated to France and Spain and returned to Britain around 12,600 BP. Britain was occupied during the Windermere Interstadial (*c.* 12,000 BP) but abandoned during the Loch Lomond Stadial (11,000 BP)

The Creswellian industry was the regional variant of the Magdalenian 12,600-12,000 BP. In caves at Creswell were found a flint scraper and burins on the end of long blades. The people who lived here hunted mainly deer and wild horse. There is also a cave painting in Creswell Cave and various engravings on bone. Further cold conditions meant that the humans moved back to the warmer southern parts of Europe and did not return until around 10,000 BP when temperatures rose again to at least as high as they are today when a new Mesolithic way of living emerged.

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Book review

Evolution of Fossil Ecosystems by P Selden and J Nudds, 2004, Manson Publishing Ltd., 160pp, £19.95 (paperback) ISBN 1840760419.

Despite its rather misleading title, this well-illustrated book describes various Fossil Lagerstätten throughout the World.

Fossil Lagerstätten are deposits which contain far more complete assemblages than are usually found. They occur when some event has buried an entire commmunity in a very short period of time, before all soft parts can be degraded; thus details which are usually not evident can now be seen.

The authors describe an overview of each site: its history (who found it, worked on it etc.); its place in the stratigraphic record and a detailed description of the fossils themselves.

As well as describing the well-known sites; The Burgess Shale; Ediacara; The Rhynie Chert; Mazon Creek, Sohnhofen and Grube Messel, other, less famous, sites are also included: The Soom Shale; The Hunsrück Slate; Grès à Voltzia; The Holzmaden Shale; The Morrison Formation; The Santana and Crato Formations; Baltic Amber and Rancho La Brea.

The authors have not confined themselves to the original sites where the Lagerstätten were found. In recent years comparable Lagerstätten sites have been unearthed globally; for instance the Chaomidrazi Formation in Liaoning Province in China has produced Solnhofen-like specimens with superb preservation of soft parts. There is a map that shows where these similar Lagerstätten are located.

This book is easy to read and can be understood by the amateur as well as the informed geologist. At £19.95 it will soon be on my bookshelf.

Jane Clarke MPhil (Open)

Mineralisation and Mining at Minera, North Wales

Peter Appleton

Regional background

Mining origins

Metals have been mined in North Wales from distant times, strikingly demonstrated in recent years by excavations in the copper mines of the Great Orme's Head, Llandudno. Here radiocarbon dates circa 1400BC confirm extensive mining activity in the Bronze Age in what now appears to be one of the most important ancient mining sites in Europe. During the Roman occupation an urgent demand for lead was in part satisfied from a number of sites dotted across the uplands of north-east Wales. Evidence of the discovery of coins and 'pigs' of lead with Roman inscriptions, indicates that the main producing areas at that time were around Prestatyn in the north and on the high ground between Holywell and Halkyn in the centre of the region.

Geological history

Most of the lead/zinc production in North Wales arose from fissure veins hosted by carbonate sediments of the Dinantian (Carboiferous Limestone). The eastern outcrop was the most important extending southwards from the coast and flanking the eastern slopes of the Clwydian Hills (Figure 1). Twice stepped eastwards by major faulting the outcrop terminates at Llanymynech in Shropshire, a total distance of forty miles.

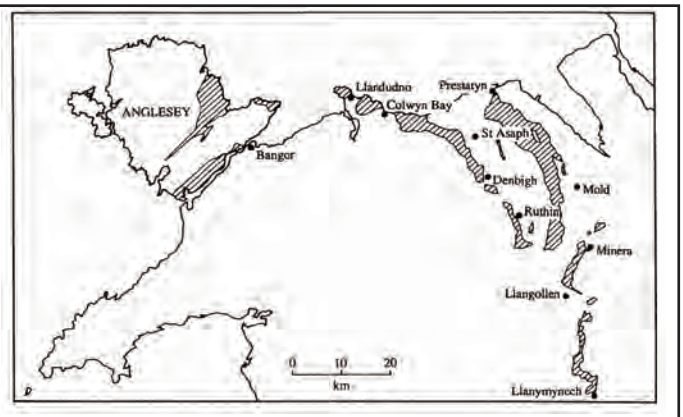

Figure 1. Outcrop of Dinantian rocks in North Wales.

The Dinantian sequence records the progress of a marine transgression, which encroached on the northern flank of the Wales-Brabant Massif ('St George's Land'), an upland area of Lower Palaeozoic rocks represented today by the Snowdonia Mountains. The process followed an extended period of erosion initiated during the mountain building episode of the 'Caledonian Orogeny', itself the result of continental collision, deformation and uplift consequent on the closure of the ancient Iapetus Ocean.

The region's Dinantian rocks are a thick sequence of marine ramp and platform carbonates deposited in shallow-water under tropical conditions. Termed the 'North Wales Shelf' they were emplaced between the land and the deeper water of the former Craven / Irish Sea Basin to the north. They lie with marked unconformity on folded Silurian and locally Ordovician rocks. The observation that beds of particular lithology are repeated in a regular way indicates cyclicity in the processes of sedimentation. Cycle boundaries typically appear as prominent bedding planes, they frequently show evidence of palaeokarstic erosion and might be accompanied by a volcanically derived bentonite clay or 'palaeosol'. Thus it is concluded that the Dinantian inundation was episodic in nature, punctuated by periods of regression. The occasional presence of carbonaceous partings at such horizons indicates that emergence was sometimes of sufficient duration to establish a vegetation cover.

The nature of deposition in the Dinantian owes much to the structural framework inherited from the Caledonian Orogeny, which created a tectonically moulded surface of blocks and basins. Large variations in the thickness of Dinantian rocks are due in part to the undulating surface of the submerging landscape giving a coastline of bays and headlands. Recent analysis suggests that contemporary movements across major fault lines, including the ancient 'Bala Lineament', also had a significant bearing on sedimentation. These situations have led to 'overlapping' of earlier by later sediments, a case in point being a thickness variation of from 150 to 400m between the southern rim and the trough of the Llangollen syncline, a distance of only three miles.

Mineralisation

In the late Carboniferous uplift of the region took place, a consequence of the Variscan Orogeny. It was during this period that the structure and fracture patterns of the mineral districts were defined. Orebodies within the North-East Wales mining districts (Figure 2) are generally confined to simple fault fissures; tension fractures more or less parallel to the dip direction, north-west to south-east in the area described. The lead-zinc mineralisation is of the Mississippi Valley Type, similar in most respects to that of the Northern Pennines and the Peak District. It has been proposed that the metals have been carried within sodium chloride brines expelled by the tectonic compaction and diagenesis of muddy sediments in the Irish Sea and Cheshire Basins. The solutions have permeated favourably disposed fractures within the fringing shelf limestones, where the principle ores, galena and

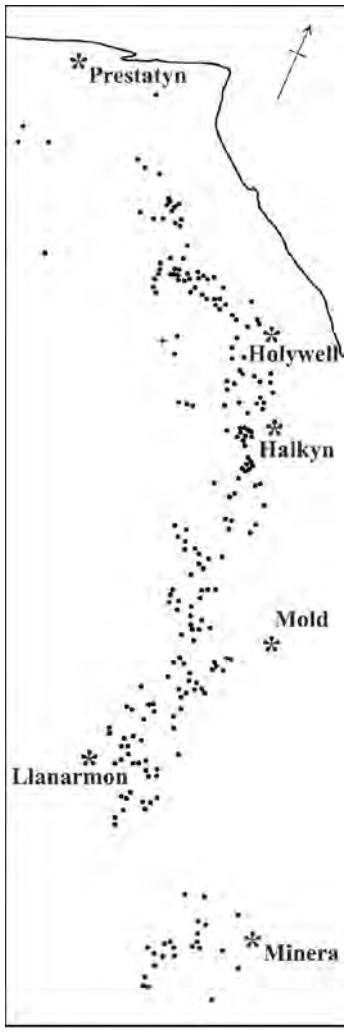

Figure 2. Locations of former mines as a guide to the extent of lead-zinc mineralisation in the eastern limestone outcrop. (After Lewis 1967)

sphalerite are found as veins accompanied by calcite and infrequently by quartz. The precipitation chemistry of the sulphide ores appears to be a matter of debate but necessarily must have occurred in an environment involving a source of sulphur.

Minera District

The location

The village of Minera lies in the wooded valley of the river Clywedog, some four miles west of the town of Wrexham in North Wales. The Minera mining field is compact and occupies the northern part of a six-mile, ribbon-like outcrop of Lower Carboniferous rocks, which is truncated in the north by the Llanelidan fault, a component of the 'Bala Lineament'. To the south, the whole 360m of the limestone sequence is revealed at Eglwyseg in a spectacular series of scarps, terminated dramatically high above the Vale of Llangollen at the Aqueduct Fault. The 'Eglwyseg Escarpment' was an inspiration to George Morton, a nineteenth century, pioneering geologist, whose meticulous studies culminated in the first comprehensive stratigraphy of the Carboniferous Limestone in North Wales.

The rocks

In the Eglwyseg sequence Morton (1878) recognised five distinct formations within the Carboniferous Limestone, these and the modern equivalents of the BGS are shown in the table below. Approaching Minera in the north, the Basement Beds and the greater part of the Leete Limestone are overlapped across a rise in the Lower Palaeozoic topography coinciding with the structural high of the Cyrn y Brain anticline.

Morton; 1878	BGS / Somerville & Strank; 1984	Stage
Cefn y Fedw Sandstone	Cefn y Fedw Sandstone	Namurian
Sandy Limestone	Minera Formation	Brigantian
Upper grey Limestone	Cefn Mawr Limestone	
White Limestone	Loggerheads Limestone	Late Asbian
Lower Brown Limestone	Leete Limestone	Early Asbian
Basement Beds	Basement Beds	Holkerian ?

The unconformity with the Lower Palaeozoic is well displayed in Minera Quarry, where an undulating and furrowed surface of cleaved Ordovician mudstone underlies pebbly limestone containing the brachiopod *Daviesiella llangollensis*, diagnostic of the Leete Limestone. The formation is a thinly bedded sequence alternating between dark grey bioclastic limestone and micritic 'porcellaneous' limestone with thin shales and bentonite clays. The Loggerheads Limestone is generally a light grey biosparite, the thicker beds forming the bolder outcrop features of the district. The apparently truncated sequence of 60 metres is well exposed in the Minera Quarries and contains palaeokarst surfaces and conspicuous bentonite clay horizons. Fossils are scarce though gastropods and productid brachiopods are sometimes found. The Cefn Mawr Limestone is a series of thin to medium-bedded, dark grey, bioclastic limestones, with interbedded shales becoming more prominent in the younger parts of the sequence. Some beds are particularly fossiliferous, notably the 'coral bed' at the top of the sequence and a bed full of crinoid debris some few metres below. Two shales, each about 8m in thickness, are persistent features in the upper part. A rich shallow water fauna of corals, brachiopods, crinoids, bryozoans and occasional trilobites was formerly collected at Minera. Overlying the Cefn Mawr Limestone are sandy limestones, mudstones and sandstones of the Minera Formation forming the elevated scarp above the village.

The minerals

The ore minerals of commercial interest at Minera were galena and sphalerite. Smithsonite occurred in the higher parts of some veins, notably at the Park and Pool Park Mines, but seldom in workable quantities. Chalcopyrite is recorded, but only in tiny quantities. There was an obvious zoning of the lead-zinc mineralization with depth. Sphalerite, little more than a curiosity in the shallower western parts of the mine, gradually increased in abundance with depth, until at the deepest parts of the mine in the southeast, the ratio of zinc ore to lead ore raised was ten to one.

Figure 3. Quartz from the White Vein, Minera lead Mines.

Unlike most areas of Mississippi Valley Type mineralisation in North-east Wales, where calcite is the sole gangue mineral, at Minera quartz predominates (Figure 3). It occurs massive, well crystallised in the many small vugs, or finely crystallised resembling blocks of salt. Silicification of wall rock is common. Calcite also occurs, the common form being six sided prisms surmounted by a flat rhombohedron (Figure 4). Sometimes crystals are shot through with specks of chalcopyrite and malachite.

Figure 4. Calcite from the Busy Bee Vein, Minera Lead Mines.

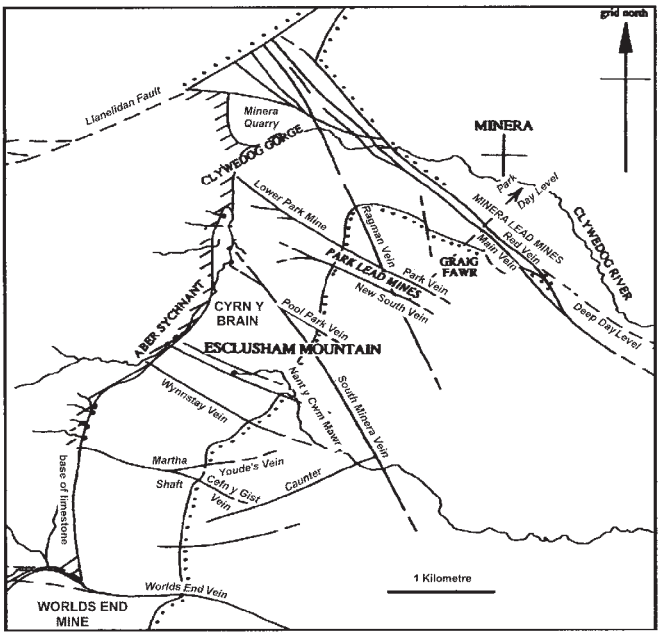

Figure 5. Sketch map of veins in the Minera Mining Field.

The veins

Workable orebodies were found in fault fissures occurring as far south as World's End, but the richest mines were developed in the complex Minera Fault Zone, consisting of two main NW-SE fractures with a downthrow to the north-east (Figure 5). The combined displacement across these fractures is untypically large for lead-zinc veins in north-east Wales being up to 500m at its maximum. The fracture on the north side is known as the North or Red Vein, while that on the south is known as the South or Main Vein. The Main Vein has many branches especially in the northwest, where its identity is lost in a spread of veins, which all terminate at the Llanelidan Fault.

The veins were productive throughout the limestone strata and workable deposits were sometimes found in the overlying Cefn y Fedw sandstone. Yields fell off rapidly, however, as the underlying Ordovician shale or 'bluestone' was approached. There is evidence from the Park Lead Mines that thick shale beds in the Cefn Mawr Limestone produced local enrichment due to clogging of the vein fissures and 'ponding' of mineralizing solutions, as in the mines in the Holywell-Halkyn area, but in the major fractures at Minera this effect was much less important. In working the western mines many ‘flat’ veins were discovered, which were reputed to have been very rich. Recent examination has confirmed the great extent of these workings. Some of the flats were found to occur at bentonite clay horizons in the upper part of the Loggerheads Limestone. Other flats were associated with low angle movement along bedding planes, 'slickensides' being a prominent feature on the roofs of some of these old workings.

The mines

That the Romans mined lead at Minera has long been inferred; the mineral veins would have been easily discovered at outcrop, a Roman road passes close by, and residues of lead smelting have been recorded in a Roman context only three miles distant. Proof remains elusive though ancient working is inferred by the discovery of a stone mortar (Figure 6) in workings 50 metres below surface in 2005.

Figure 6. Stone mortar from Minera Mines

The earliest documentary evidence refers to a flourishing mining industry around the year 1301. Thereafter mining seems to have proceeded sporadically through late medieval times. It is likely that these early workings were in the north-west in an area known as ‘Top Eisteddfod’. The ground is 'pock-marked' with run-in shafts and waste hillocks, where the spread of veins was worked at shallow depth on the outcrop of the productive horizons in the Loggerheads and Cefn Mawr Limestones. In their 1995 survey of metal mine sites in mid and north-east Wales, the Clwyd-Powys Archaeological Trust said of the ‘Top Eisteddfod’ area, “This extensive well-preserved mining area is of unique archaeological and historical importance in Wales”.

By the start of the eighteenth century there was a strong Cornish influence in mining techniques; much expertise and capital came to Minera from outside the area. In about the year 1720 mining began in a systematic manner, starting where the ore-bearing strata were still at a modest depth in what became known as the West End Mine; deeper shafts were sunk and horizontal tunnels driven to intersect the lead veins. Mining gradually extended eastwards, the ore being followed to deeper levels with the dip of the productive horizons. Several separate companies were involved in the working of the mines and all these ventures seemed to have been successful. In the latter half of the eighteenth century, however, the West End Mines suffered increasing water problems. Hitherto waterwheels had provided the power for the pumps but in 1783 it became necessary to install a Boulton and Watt pumping engine. Though a second engine was commissioned a few years later, in 1799, with the workings only 80yds deep, the situation was described by James Watt Jnr (1799) as follows: 'All the workings below (adit) level upon these different veins are inundated with water in wet seasons, and the engines sometimes overpowered; the waters are supposed to accumulate in a natural cavern in the side of the hill of Craig Vawr to the south of the valley, and thence to penetrate through the fissures in the rock into the mine.' With the extension of an adit level to the cavern and the erection of a third engine considerable quantities of ore were raised until about 1817 when increasing pumping costs and breakdowns rendered the enterprise uneconomical.

The mines at the east end of the Minera veins were worked separately, there being a section of unworked ground between them and the West End Mines about 500m long. The East End Mines had their own pumping engines and adit system and were worked very profitably until 1815 when 'swallows' were intersected in one of the veins at the '170yd level', allowing water to pour into the workings from the west. In 1816 seven pumping engines were at work in different parts of the West and East End Mines raising a total of 4000 gallons of water per minute and consuming over 300 tons of coal per week. With little co-operation between the several proprietors over drainage, mounting financial problems and lengthy litigation the last of the Minera Mines closed by 1824.

In 1849 leases were taken up for the whole of the area occupied by the old mines, and the Minera Mining Company was formed.

Figure 7. Stopes in the Busy Bee Vein, Minera Mines.

Under the able stewardship of the great mining engineers, John Taylor and Sons, an immensely successful period of 30 years followed. Deep drainage was secured by a day level brought up to the east end of the property and extended over the next 10 years to intersect the fissures which poured water into the mines at their western extremity. During the course of this drivage several rich runs of ore were located (Figure 7). In the east the mine was developed down to the 270 Yard level from several shafts. Shallower levels were extended through previously unworked ground into the old western workings. Skillful planning by the new company in its early years was a major factor in Minera's rise to become Britain's leading producer of lead and zinc ores in the 1860's and 1870's.

As the years went by reserves of lead ores in the western and central parts of the mine became exhausted. Some sections were reopened to extract zinc ore, which, being of lesser value, had been left in the workings; from 1880 the tonnage of zinc ores raised exceeded those of lead. Development proceeded at depth in the eastern ground the main winding shaft being deepened to the 430 Yard level (Figure 8). In the 1890's the veins still further to the east were exploited from a new sinking called, the New Minera Mine. The quantity of zinc ore raised from these deepest workings outweighed that of lead by ten to one. By the earliest years of the 20th century it was this fact coupled with low zinc prices and increasing mining costs, which led to cessation of pumping and abandonment of the deep workings in 1909. Mining continued on a smaller scale above the rising water level until the mines finally closed in 1914.

Judging from the large scale of older workings and the incomplete production figures now available, it is likely that the quantity of lead and zinc concentrates produced in the 200 years up to 1914 amounted to over 400,000 tons.

The present

The Wrexham County Borough Council runs a visitor centre at the City Shaft and dressing floors. Further interpretation work is contemplated as part of a project to regenerate the Minera Quarry area by the Minera Quarry Trust.

Figure 8. Winding at the City Shaft, the centre of activities at the Minera Mines in the 1890s.

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Author

Peter Appleton is a retired metallurgist with a lifelong interest in geology and underground exploration. He has been deeply involved in the exploration of historic mines and in the discovery and mapping of limestone caves in North Wales.

Within This Hill

Rob Heslop

Standing isolated, the jagged Serre-de-Guercy hill looms above the Rhône river to the west and is hemmed at the east by the deep 'Dead Valley of Toulard'. Squeezing from the north we find a place called Hell's Ravine. Upon this hill seven caves lead toward a matrix of remnants from the Quaternary including Neanderthal, mammoth, hyena and cave bear.

I spend the summer treading the hill as a guide for the handful of tourists that happen into the web; here nature harbours all for the naturalist and geologist, archaeologist and prehistorian alike.

Figure 1. Serre-de-Guercy hill.

I leave Lyon one early spring morning and drive south to the department of Ardèche. A little further from the industrial bustle of Valence I enter the northern parts of La Provence. Welcome to the land of Big-Sun, a vast and arid-scape of tiny wild flowers and alpine herbs. I follow rolling hills lined by Côte-du-Rhône vineyards, and after Hell's Ravine negotiate Soyons village before parking a little further on at the foot of Serre-de-Guercy (Figure 1). This is busy-early-morning-week-day and as modern civilization rush and jam to unknown destinations, the small Serre-de-Guercy carpark stands empty; the ancient hill is thus desolate. I set off and up on a steep hike towards the tops contented to proclaim the hill as mine!

The earliest traces of Neanderthals at this site go back perhaps 110,000 years, to a diminishing ice-age period of Riss tundra (mid- Palaeolithic). At this time, Neanderthals were the only form of human living in Europe. The various karstic caves at Guercy were seasonally squatted by these peoples for several tens of thousands of years, and shared with boisterous cave bear (*Ursus spelaeus*), lion (*Panthera spelaeus*) and hyena (*Hyena spelaeus*).

Later, sometime during the late Palaeolithic of 40,000 years another type of human, Cro-Magnon, known as early-modern man, migrated across Europe and ventured into the territorial vast lands of the Neanderthals, they too settled at the Guercy caves, as fossil bone and flints found here have shown. For a duration of approximately 15,000 years, Neanderthal and Cro-Magnon peoples lived as contemporaries all over Europe before the Neanderthals finally disappeared, but in what way the various communities shared the land during that time remains unclear. Speculation on this question is rife … at the Serre-de-Guercy was there confrontation upon this hill? And when exactly and why did the Neanderthals leave; were they simply replaced by more efficient peoples?

Many ages after, Neolithic nomads left their indication of passage as enigmatic burials in several of the caves dating to approximately 2000 BC. Then more recently, the Iron Age peoples built a settlement (*Oppidum)* on the highest point of the hill, with the oppidum later converted to Romanisation, as the latins spread northwards.

Whilst contemplating the passage of continuous human history upon this massif, I explore the rugged landscape, and as a backdrop to it see the shimmering Rhône as it meanders way off to the south. The sharp Vercors mountains dominate the eastern horizon. Following a trail I take a left and pass a sturdy pine before seeing a sign indicating the first cave, Nerons. This large cave was partially excavated during the end of the 19th century; masses of Palaeolithic fossils were uncovered including human remains. Sadly however, most of these finds were exchanged or sold off to private collectors. Other caves were then investigated before being sealed behind iron doors, such as the Fox Hole cave, (Trou de Renard), Sheep's Hole (Trou du Mouton), Roland's Hole (Trou Roland), the Madelaine and recently, the Moula Shelter; a major Neanderthal findspot.

Figure 2. Nerons Cave.

It is from within Nerons that the summer visitors are first guided back to prehistory (Figure 2). Further excavation was carried out in this cave in 1993 by a group of scientists from the university of Marseille and, despite the early haphazard pillaging from the previous century, these digs managed to reveal early human 'living floors' which had remained intact about a metre or so under the rubble and silt of ages. Carbonised wood fragments were recovered from several ancient burnt-out hearths, and were later identified as juniper and scots pine remnants as well as birch. Detailed investigation of these reminders tells us of a cold dry climate, typifying an open steppe landscape. The whole sequence gave a C^{14} date of approximately 43,000 years. Mingled with these hearths were hundreds of hand flints and shards from them, which have

been identified as coming from a Neanderthal industry known as the Mousterian (Charentian complex). Indeed, two Neanderthal teeth were also recovered entwined amongst the debris, as well as fossil bear, reindeer, horse, deer, lion, steppe bison and beaver. Are we to understand that these early hunter-gatherer peoples trailed the steppe as nomads, perhaps following the large migrating herds of the dying Palaeolithic period, stopping in this shelter as a regular, perhaps yearly halt? Several other interesting palaeontological horizons were found beneath the human surface, such as a well-preserved hyena den revealing even fossilised dung, known as coprolites.

Nerons is a massive cave. At the far end of it a passage leads on to another cavity known as the Cathedral. I ventured into this 'secret' passage one Sunday morning with fellow guide Marie, a young jeans and trainers lady, and Fanny, head site archaeologist. Kitted with hard hats and torches we crept through mud and filth and silt, eventually finding the high and cold Cathedral. We wander in but after only 10 metres large rocks, boulders and sediment pile the floor to such a height they have blocked further access; behind this barrier further cavities lie hidden. Before leaving this dark and forbidding cave, our torch lights reveal rows of parallel engravings upon the vertical walls; these are ancient claw marks left by cave bear many millennia previously.

Figure 3. Sealed: the Fox Hole.

After Nerons tourists are shown a second cave, the Fox Hole. A steep iron stairway leads down to the sealed entrance (Figure 3). This shelter was also excavated by early archaeologists, and revealed similar relics to Nerons, as well as rhino and mammoth fossils. The back of the shelter had been blocked by a massive roof fall not unlike that of the Cathedral; this was cleared in 1970 revealing a chamber of great geological interest, the Double Borne gallery, which is over 100 metres in length. Spectacular, this gallery contains stalagmites, stalactites and translucent soda-straw formations as well as various extraordinary calcite build ups of many-a-colour. At the end of the gallery a massive profusion of calcite accumulation has created an enormous pillar holding floor to ceiling; it has been estimated at 250,000 years old. Indeed, the

Figure 4. The Double Borne gallery from Fox Hole.

flowstone build up throughout this whole corridor seems to have done just that, hold the ceilings, thus seemingly breaking the rules of karstic collapse and continued slow movement (Figure 4).

It is perhaps due to this phenomenon that a passage named the 'Reseau Ursus' remains *in situ*; Reseau Ursus was recently discovered running under the Double Borne structure, and is preserved precisely along its same course. I visited this secluded out-of-bounds reseau, again with Marie and Fanny early one morning, and after scrambling down a vertical shaft of two metres from the eerie silence of Double Borne, we lay crowded into a tiny horizontal tunnel and blazed our lamps into a helter-skelter obscurity; there, perhaps fifty metres ahead lay an entire gigantic bear fossil, its old bones fluorescent white against a timeless blackened abyss. Scientists have already examined this reseau, but taken very few relics from it due to lack of funding, thus leaving the vast proportion of this ancient bear's den, dated at 150,000 years, intact. We dragged ourselves deeper. Fallen, short but large stalactites hinder the passage, and precarious, un-glued stalagmites lay over mammal bones of all sorts. Fantastic, we even see a tiny baby hyena jaw, mingled amongst the debris of fossils a thousand fold (Figure 5).

Figure 5. The author (left) and his brother at the concealed Ursus tunnel.

Just opposite to the vertical entrance of Reseau Ursus, a large metal pipe protrudes from the floor of Double Borne; this nifty air duct leads to yet another newly found cavity called the Moula Shelter (Figure 6).

Figure 6. Within Moula Shelter, preparing for the digs.

This cave has been under excavation since the early 1990s when a mixed team of searchers from the university of Marseille, and Berkeley university, USA, dug and scraped the floors of the shelter. Before doing so however, machinery was hoisted by helicopter to the Guercy hillside, including a small bobcat digger, for the Moula Shelter had no direct passage to the exterior; it had to be cut from the rock. Discovered due to a draught of air sweeping from the shelter into the Double Borne, this has proved to be a most incredible find indeed. In all, six Neanderthal individuals have been exposed, their fragmentary remains lying haphazardly scattered around an archaeological horizon, together with remnants of red deer (*Cervus elaphus*) and flint scrapers of the Mousterian (Ferrassian) type, somewhat similar in technological style to those found at Nerons cave. Dating analysis shows these relics to be of around 110,000 years old. The mix of fossils found in this context has revealed clear scars of flint cutting traces upon the bone pieces, inferring to butchery of the victims found here, both deer, and ancient human alike; this is a Neanderthal cannibal site. Other such sites from Europe are well known: Krapina in Croatia, Zafarraya from Spain and Combe Grenal, France. Did Neanderthal eat Neanderthal through necessity?

Other fossils were recovered from this stratigraphy, as well as traces of three hearths and the remainder of what seems to be a separating cobble stone wall. The Moula Shelter has been more or less 30% excavated to date; but for several years now the digs have stopped.

Further excavation, research and analysis is needed, for without doubt deep under the remaining earth-of-ages and limestone boulder, grubs and bat midden, lie other fascinating indicators of Neanderthal during this, a rare context of interglacial, known as the Riss-Wurm, which is now understood as being a cold and changing landscape. Within this hill at that time and indeed much later, the strange Neanderthals found refuge.

Whilst leaving the Guercy hill, and after a short steep scramble, I find a large open cavity and venture into the silent, dank, dark, high and wide environment, (Figure 7) another grotte Neanderthal? Possibly. Moss thrives in one corner as water drips from the Narbonnais limestone ceilings. The surface of the cave is piled with fallen limestone slabs. Turning my back to the cold dark and still recess, I squat near the entrance and admire the massive sedimentary Valence flats which remain forever shadowed by the Vercors; who else has shared this very same moment? At this entrance way up high above the river, I imagine, then see slow

Figure 7. Sheep's Cave; another Neanderthal site?

Palaeolithic herds moving upon the tundra of the lowland flats, and I clearly see the beautiful early peoples of Neanderthal, rugged and hardy, they were artisans and supreme hunters; it is from this fleeting instant that I admire the Stone Age indigenes as masters of an ancient and hostile wilderness.

Somewhere lost deep inside these long and still caves we find other times all seemingly held and captured without motion. Only the 'outsides' see each and every new day as a ticking and guiding rhythm for life. Back deep down within, early human passage, complete with their behaviour patterns and gesture and almost sound, lie piled together with the claw marks from thriving landscapes now long since gone. Together as a mingled mess, stone tools and bone tools, flints and flakes are forever frozen in the single night of eternity. Thrown and forgotten, cast dead still and inert as if the ancients had only just gone.

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I visit an old house at Soyons near the railway, where a young scientist works alone on the second floor, his task; to catalogue masses of objects gathered from the hill, Roman and Iron Age relics from upon it, and masses of Quaternary fossils from within it. Upon a table, a 100,000 year old juvenile wolf fossil crumbles simultaneously with the large rock in which the bones are held. A rounded bear's skull looks down from a musty shelf. Cardboard boxes are piled to the rim with a knot of fossil bones, disintegration seemingly the only promise for their future, each and every one.

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Geologies around Guercy

A varied mix of Miocene sediments pile the foot of Guercy. The hill rises to 245m and is packed with Kimmeridgian and Oxfordian rock, also called Narbonnais and Crussol limestone. The hill of Guercy is overshadowed by an ogre of over 400m called Mount Crussol, where many more Jurassic strata jostle.

Hell's Ravine slices the Mount Crussol from Serre de Guercy. This geological fault splits deep revealing Argovian stratigraphies at the highest point; Oxfordian, Bathonian and Bajocian chapters

follow until, just under the silt of the ravine, Triassic rock can be found. Traces of Rauracian limestone can be recovered, with some of those exposing small ammonites of *Perisphinctes* and *Phylloceras*.

The opposite side of the Rhône tells a different story: that of recent glacial passage dating to the Wurmian (British Isles; Devensian), which created the large lowland Valence Flats.

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Many thanks to Fanny Deryme

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Author

Forever passionate for prehistory, landscape and wilderness environments, Rob left the UK 20 years ago for France as a watercolour landscape artist. He learnt French off-hand and settled near Lyon with Anne, a musician. He works as a teacher, studies (Long Distance) archaeology with Exeter University, participates on various digs as well as doing guide-work within Guercy. He enjoys researching and writing and has to date compiled 20 short works, which he calls the Land-Trek-Series; ranging from fossils and natural history, to exploring Roman field systems. He is looking for an editor. He has been a member of OUGS for many years.

Book reviews

Hydrogeology. Principles and Practice by Kevin M Hiscock, 2005, Blackwell Science Ltd, 389pp, £34.95 (hardback) ISBN 0632057637.

Hydrogeology is an interdisciplinary subject which has applications to water supply and contamination as well as many currently sensitive environmental issues such as waste disposal, the impact of global warming and wetlands management. First defined by Joseph Lucas in 1877, it covers the occurrence, distribution and movement of groundwater as well as its interaction with both natural and anthropogenic materials within the crust and biosphere. This book, written by Kevin Hiscock, a teacher and researcher at UEA in Norwich, discusses the principles of hydrogeology and the importance of groundwater as a finite and vulnerable resource. This vulnerability is well illustrated by the low groundwater levels, and consequent water supply problems, which affected SE England and adjacent parts of continental Europe during the summer of 2005. Early chapters in the book cover fundamental material in physical, chemical and environmental isotope hydrogeology. This is followed by an examination of groundwater investigation techniques and a full treatment of contaminant hydrogeology and the principles underlying remediation and protection. A feature of the book is that many of the case studies used to illustrate the text are based on work in the UK and Europe, a refreshing change from comparable texts, which tend to be written from a North American perspective. Each chapter concludes with recommendations for further reading and an appendix provides a series of exercises for students to test their understanding.

The book is well illustrated and throughout the text boxes are used to explain specific topics and to illustrate case studies. Some of these "boxes" continue for up to three or more pages and are followed almost seamlessly by other "boxes". I found this rather confusing and I would have preferred to see material from many of these boxes, particularly those which illustrate specific topics such as flow nets, saturation index etc., incorporated into the text. However my principal quibble with this book is that it takes a very traditional approach to hydrogeology, concentrating almost solely on permeable rocks. The properties and role of poorly-permeable rocks, and the extensive work carried out within radioactive waste programmes is not covered, but should be incorporated into any modern hydrogeological textbook.

Despite these concerns this book is a useful and accessible addition to the literature available on hydrogeology. Introducing Groundwater by Michael Price provides a sound first year undergraduate text and is complemented by this book, which represents a more advanced undergraduate and postgraduate text, also of use to practising professionals. A copy will definitely be a fixture on my bookshelf, not least for the selection of useful case histories which it contains.

John Mather, Family member of OUGS

Fossil Invertebrates by Paul D Taylor and David N Lewis, 2005, Natural History Museum, 208pp, £25.00 (hardback) ISBN 0565091832

This well illustrated book covers all major groups of fossil invertebrates and includes reference to the links between ancient and modern organisms. There are six chapters, the first being a basic introduction to fossils and invertebrate animals, with sections on the rocks in which they can be found, how they formed, their preservation and dating. The geological timescale is explained and there is a section on invertebrate diversity through time.

The following five chapters deal with the major groups of fossil invertebrates and at the end of each major section of text there are brief descriptions and illustrations for some characteristic fossil genera. The authors point out that these are not intended to be comprehensive and that specialist texts should be consulted for identification purposes. Chapter 2 deals with those creatures that lived in colonies, describing their feeding, growth, lifespan and physiology: there are four major sections describing corals, bryozoans, sponges and graptolites. There is a useful table for distinguishing between fossil coral orders and the section on bryozoans includes a classification with their geological ranges. The section about graptolites starts with the amusing reference to the student prank of trying to pass off a pencil line drawn on a piece of slate as a fossil graptolite.

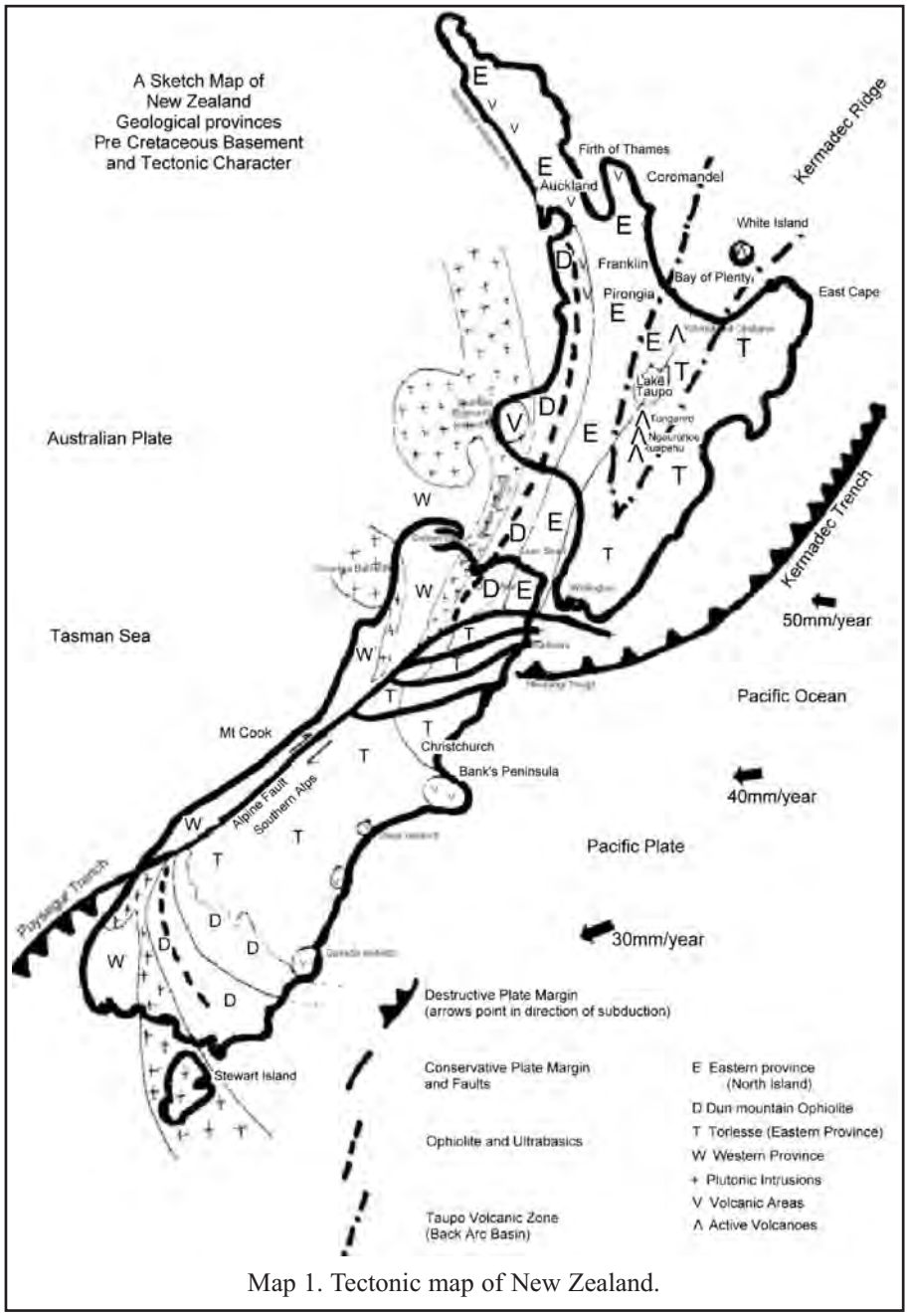
Two major groups, Molluscs and Brachiopods, are covered in Chapter 3 entitled Shells Galore. The section on molluscs deals with the three major classes, bivalves, gastropods and cephalopods, including the very popular ammonites. The authors point out that brachiopods have been extensively studied because of their abundance in the fossil record although today they are uncommon and out of the 4,500 genera that have been described 95 per cent are extinct. Worms and tubes are the subject of the relatively short Chapter 4 and there is an interesting paragraph about the giant worm, Riftia, first discovered in 1977 around hydrothermal vents in the Pacific Ocean. My personal favourites, trilobites, are the subject of Chapter 5 called Jointed-limbed Animals. Also described in this chapter are Chelicerates, the group of arthropods that contains spiders, scorpions, horseshoe crabs and an extinct group called eurypterids and the chapter ends with a section on Insects. The final chapter, Spiny-skinned Animals, is about echinoderms and includes echinoids and crinoids.

No prior knowledge of the subject is assumed and the text throughout the book is very readable. The exellent illustrations are in black and white but in the centre of the book are sixteen pages of superb colour photographs. A page of Further Information includes a list of books and websites and there is a five-page index. For such a beautifully produced book in hardback it is very modestly priced and would be an ideal resource for any undergraduate or amateur fossil enthusiast.

Elizabeth Maddocks, BA (Open)

Scratching the surface of New Zealand: North Island

Robin Lewando



Map 1. Tectonic map of New Zealand.

New Zealand is the higher ground of an area of continental crust lying astride the Pacific and Australian plate margins. The total area is about one third the size of the Australian landmass. It is fairly unique in the world for being a country lying completely within its own continental crust, bounded all round by ocean, and neatly sliced in two by a major and very active plate margin (Map 1).

New Zealanders talk of their country as being young. Abel Tasman is considered the first discoverer of these islands in 1642 and Cook the first to map the whole coastline in 1769/70, followed by planned settlement from about 1840. It has been a separate landmass only for the last 80 million years when this continental crust broke away from Gondwanaland as the Tasman Sea formed, so in both respects it can be thought of as young. But the basement rocks date back, in the Western province, to Cambrian times.

The delineation of this area of continental crust is the subject of the New Zealand Continental Shelf Project and UNCLOS (United Nations Convention on the Law of the Sea) article 76 to try to extend territorial rights. Both the extent and position of this area of the earth's crust, as well as the geological history, make this an area well worth studying, and I took advantage of a visit in April and May 2004 to investigate as much of this fascinating area as possible.

The flight from Heathrow to Auckland took around 24 hours, excluding the four-hour stop at Singapore, a large proportion of this time being spent in darkness. By the time I reached New Zealand the sky was blue and the sun was shining - above the low cloud which covered the Tasman Sea. Mt. Egmont, otherwise known as Mt. Taranaki, was visible away to the south, protruding through the cloud in snowy and majestic splendour. As we came in, dropping down through the cloud, we emerged at 3000 feet to see the coloured roofs of Auckland spread out beneath us.

A whistle stop tour enabled me to count 13 of the 48 existing volcanoes in the Auckland volcanic field amongst which the city is built. The volcanoes of Auckland were all formed within the last 60,000 years, the most recent being Rangitoto which formed in an eruption 600 years ago. The highest is Mt. Eden, at 196m, from the top of which there is an all-round view of Auckland. The incredible 50m deep, cone-shaped crater on the summit now entirely grassed and grazed by cattle is carefully preserved.

I was heading some 50 miles south of Auckland to a place called Pukekawa, which in Maori means Bitter Hill as it was the site of some fierce inter-tribal battles. Its modern claim to fame is as the location of the Pukekawa murders. It was here I experienced my first taste of native bush. This was a delight, being full of trees which were unfamiliar to me, tough black-stemmed Supplejack creeper (*Ripogonum*), *Cordylines* (otherwise known as cabbage trees), and those wonderful *Sphaeropteris* and *Dicksonia* tree ferns which made the whole trip to New Zealand more exotic and entrancing by their beautiful shape and colour. Fantails, little birds like wagtails, flitted closely around twittering and fanning their tails – hence the name - in their search for insects disturbed by our passing. It was here I acquired my first geological specimen in the form of a lump of pyroclastic rock. The rock in this area is basalt agglomerate of lower Quaternary age, all part of the Auckland volcanics. Pukekawa Hill is in fact a scoria cone, one of 80 small volcanoes in the Franklin Volcanic Field which erupted between 1.6 and 0.5Ma ago. These volcanics are the visible expression of a

Figure 1. The black magnetite sand beach at Port Waikato.

hotspot that originated further south and, migrating north, gave rise to the Auckland volcanic field. The whole Franklin district, centered on the town of Pukekohe, is consequently very fertile and grows a large amount of fruit and vegetables.

From there I took myself off to the beach at Port Waikato (Figure 1). This is at the mouth of the Waikato, a large river sourced in Lake Taupo which drains the north-western quarter of North Island below Auckland. The mouth of the river is deflected north by an area of sandbanks and dunes well known for the wild lupins that grow there. Seaward of the dunes is a beautiful long beach of largely black sand, being rich in magnetite derived from the drainage basin of the Waikato. The drive to the beach is along the edge of the river valley with the flat valley bottom to the north. To the south there are hills of upper Jurassic tuffaceous sandstone and siltstone, largely grassed and farmed, with bush on the steeper slopes and in the dells. The landscape is not dissimilar to England apart from being more accentuated in relief, though massive tree ferns serve to constantly remind one that this place is unique and special. Houses and small farms are also dotted alongside the road in a very picturesque and un-English manner. Although it was the start of autumn there was little to suggest that summer was over apart from the few trees that were changing colour, and the poplars, all of which had lost all their leaves. This road leads to Port Waikato which is in fact a small seaside community with access to the beach. The area is known as Waikato Heads. There was a shallow earthquake there in 1891 which is thought to have been somewhat less than magnitude 6 but was still the most intense historical earthquake of this western North Island area, causing shaking from Kawhia Harbour 50 miles to the south, to Auckland 50 miles to the north. On this western side of North Island the descending Pacific plate potentially gives rise to earthquakes at depths of over 200km, but this was a shallow quake of less than 40km depth.

I basked in the warm sunshine, gazing out to the Tasman sea, marveling at the fact that I shared some three miles of smooth black sand with about three other people. I found some of the shells on the beach irresistible - bright purple winkle shells (*Janthina* spp), and some very curious thin shells that had the form of those later ammonites that started to uncurl –- these are the internal shells of a small squid, *Spirula spirula*, and a purple oyster shell of which both asymmetric halves were still attached. At the southern end of the beach,s the rocks start protruding from the sand and in the cliffs the Jurassic sandstone contains plentiful fossilised plant remains. These are fossilised wood and fern leaves (Figure 2).

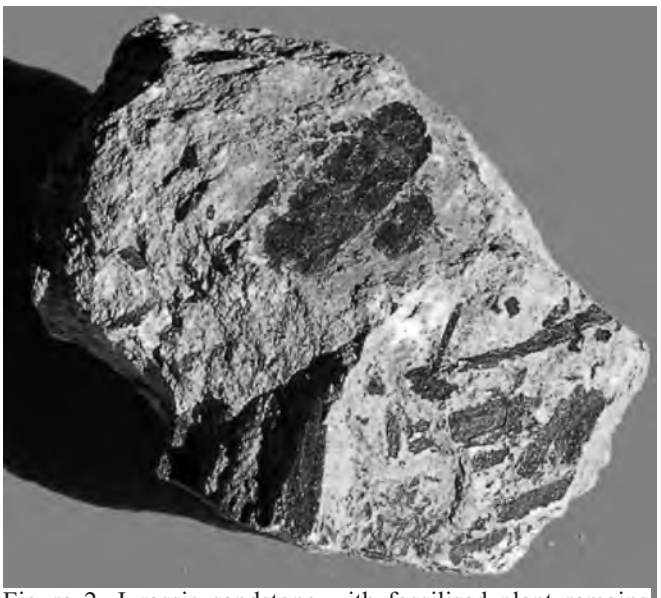


Figure 2. Jurassic sandstone with fossilised plant remains from Port Waikato.

I then took the road south to a place called Limestone Downs. Up to now roads had not been so different from those in England, but this soon changed to an unsealed road. It was still of high quality, but with obvious dangers from the loose gravel and unstable surface, not suitable for braking or cornering at speed. The road followed the coastline some one or two miles inland, through some breathtakingly beautiful limestone scenery. Again, the relief was greatly accentuated, with many outcrops of rock in various forms between green grass downland and areas of bush. There was not much sign of habitation, and the road wound its way across hillsides, round bluffs, past rock faces and across valleys (Figure 3). Every corner presented a new and breathtaking aspect of surprising variety prompting innumerable photographic opportunities. The area is one of Oligocene calcareous sediments with some areas of the Upper Jurassic sandstone and siltstone (Figure 4). Closer investigation with a large-scale map of the area would no doubt provide clearer understanding of the different relief and morphology in relation to different rock types and would make a very pleasant excursion.

The next day I headed south to the famous limestone caves of Waitomo. I was so entranced by the surroundings I had missed the speed limit sign which, as the policeman who booked me pointed out, was about the size of my car! From Te Kowhai I continued south through Whatawhata.

Figure 3. A limestone bluff on the Limestone Downs Road.

Figure 4. More towering bluffs at Limestone Downs.

I passed the impressive tree-clad mountain called Mount Pirongia, an extinct basaltic-andesite volcano between 2.7 to 1.8 million years old. Continuing south through Puketotara, Tihiroa and Otorohanga I finally arrived at the village which developed around the tourist attraction of Waitomo Caves. Sitting in the sun outside the Waitomo tavern allowed a good view of the fault scarp which delineates the western side of the valley as the Waitomo river flows north. This is the Waipa fault, and the hotel sitting on the upthrown block has a commanding view over the valley, village and road.

I took a bus journey to the caves to go Black Water Rafting, here called Tumutumu Toobing. Tumutumu is taken from the name of the unsealed Tumutumu road, with Tomo, as in Waitomo and Tumu, being the Maori word for a sink hole or collapsed doline. Here wetsuits, wellies, hard hats and lamps were donned, prior to walking across the undulating grass fields amongst the sheep where sink holes of varying depth and degree of collapse provided evidence of a cave system. After descending through a wooded dell and walking across a plank bridge, there was a ladder leading down through a squeeze, into the cave.

We were a group of six and our guide knew the cave intimately. The first fifteen minutes of our two hour underground trek involved some fairly easy caving, mostly scrabbling through narrow passages during which I had time to examine the rock walls, at a distance of about six inches, while holding my stomach in and pulling myself along with my fingertips. This was yellow Oligocene limestone here devoid of fossils and rubbed smooth by water action. There were many occurrences of stal or tufa, principally as flowstone on the surfaces. When we reached the pools we lunged into inflated inner tubes and, switching our lights off, pulled ourselves along by a rope in complete darkness in order to see the glow worms for which these caves are famous. Unlike English glow worms, these are the larvae of flies that live in the roof of the cave, dangling sticky threads down for the purpose of capturing prey. As bait, they glow with a bright and eerie green light. In the darkness this made the cave roof seem like a beautiful night sky. I was informed the population had been somewhat depleted by the rainstorms and high water levels experienced in February which had washed a lot of the glow worms out, but at the height of their population it was apparently possible to read a book by the light they generated. Interestingly, a large part of their diet is their own parents, there being few other flying insects in the depths of the cave - an example of a truly closed system.

The rest of the journey underground involved swimming across wide and deep pools, further tubing, climbing along between vertical razor-sharp rocks sharpened by water erosion, and even ducking underwater to get through a sump into the next cavern. We eventually emerged into the twilight amongst those ubiquitous tree ferns and cabbage trees and a warm evening full of the sound of crickets. A hot shower was followed by a hot meal and a lazy evening spent in the bar.

The next morning I indulged in that great New Zealand traditional breakfast, bacon and egg pie and a cup of tea. Then off down the Te Anga road and the unsealed Waipuna road to the Waitomo horse trekking centre - a farm perched on the top of the limestone hills with extensive views all around, westwards as far as the coast. I had a 3000 acre estate to roam across , making use of flat areas for wild and exhilarating canters. I could certainly get used to geological trips on horseback - and managed to take in a large selection of outcrops of the Oligocene Te Kuiti formation (Figure 5), comprised of the Waikato Coal measures, Whaingara Mudstone, Aotea Sandstone, Orahiri Limestone, Waitomo Sandstone and on top the Otorohanga Limestone. The whole sequence had been deposited over some 14 million years as the swamps that covered this north-western part of North Island gradually deepened into a shallow sea and the deposits changed from erosion products from the land to shallow offshore sand, and then clear-water lime deposits. I spotted some large bivalve fossils in situ in one of the outcrops of Otorohanga limestone.

Figure 5. Oligocene Te Kuiti strata at Waitomo.

On driving back from the farm large landslips that the heavy February rains had caused were visible on the slopes across the valleys. The relief in New Zealand is very strong with deep, steep-sided valleys being actively and rapidly weathered and eroded. This is one of the most noticeable aspects of the geography of New Zealand, particularly in South Island, where the youthfulness of the countryside is characterised by the fact that few slopes, hills or mountains have had an opportunity to take on the more mature and rounded shapes we are familiar with in Britain. Rapid uplift and rapid erosion both serve to ensure that the views are breathtaking in their grandeur. In South Island this also contributes to the increased heat flow as deeper-level rocks are exposed more rapidly than they can naturally cool.

The road cuttings on the way back also allowed a view of some of the ignimbrite that overlies the Te Kuiti formation, which originated from the Taupo eruption of circa 200 AD. It is a white and dusty, very low-density, poorly cemented rock containing vesicles, rock fragments and also displaying some orange and yellow layers of the ash.

I ate lunch sitting under a tangerine tree, looking across the Waitomo Caves domain, then proceeded slowly northward, mak-

ing a detour towards Raglan to view the Bridal Veils Waterfall. This involved a ten-minute walk through beautiful untouched bush, with its heady scent of damp earth, moss, ferns, and cool rivers, to a lookout point from which the 50 metre waterfall plunged into a deep pool amongst the trees. There was a track to the poolside at the base of the fall. It was a beautiful sight, and the columnar jointing in the rocks over which the river plunged was immediately identifiable as basalt. This was deposited from an outpouring from one of the vents of Mount Karioi, dated at between 2.9 to 2.16Ma, some 20 miles north-west of Mount Pirongia and which is related in type and age. Both of these volcanoes are subduction-related stratovolcanoes.

Then came a long but peaceful drive back to Pukekawa through the late afternoon via Dunmore, Pepepe and Glen Murray .

The next day was a day trip to Rotorua. The road passed through the Hapuakohe Range, hills of Jurassic sand and siltstones, from Pokeno through Maramarua. Then on into Mangatarata, descending to the broad flat swamp deposits of the Hauraki Plain of the Waitoa and Waihou rivers. At the far eastern side of the plain is Paeroa, the antique centre of New Zealand, which also boasts a beautiful grove of Phoenix palm trees set against a backdrop of the southern end of the Coromandel Range. The road threaded between the Coromandel Range to the north and the Kaimai Range to the south, both of which are constructed of andesite flows. This led to the South Pacific coast, overlooking Tauranga harbour and the Bay of Plenty. I then followed the coast south-east through Tauranga amongst many citrus farms and packing stations, turning inland down the valley of the Pokopoko river to Lake Rotoiti, where black swans glide, then on to Lake Rotorua and Rotorua town. The lake is a caldera formed from collapse of the roof of a magma chamber some 200,000 years ago, and Mokoia island in the centre of the lake is the top of a rhyolite pipe. Rotorua town has a seaside atmosphere, with paddle steamers on the lake and an airport by the lake, pleasure gardens and a very neatly laid out town. The town lies at the southern end of the lake, and at the southern end of the town is the thermal village. Plumes and wafts of steam rise from holes in the ground, within the gardens of the wooden single-storey houses, from walled pools, underneath dead bushes, or between piles of rocks.

The Maori name of the thermal village is Te Whakarewarewatanga O Te Ope Taua A Wahiao, which means the uprising of the war party of Wahiao. After the 1886 eruption of Tarawera to the south-east destroyed the village there and killed all but a few of the villagers, those who remained left the area and settled around the hot springs where this village now is. The burial places of these original survivors are visible in the village. The 1886 eruption of Tarawera was the latest in a series of eruptions going back to some 20,000 years ago, and was particularly destructive to the rhyolite dome since some nine separate craters coalesced to form a massive rift across the volcano. The eighth wonder of the world, the Pink and White Terraces of Tarawera, were destroyed in the eruption, being terraces of minerals deposited from thermal emissions on the shore of the hot lake Rotomahana.

The roads and paths extended for a large area around the village amongst various pools, lakes and springs amongst which low bush grew. The whole atmosphere was suffused with a smell of sulphur and a peculiar awareness of the mobility of the crust around us.

Figure 6. Steaming geothermal pools at Rotorua.

The hot pools, which were many and varied (Figure 6), were respectively being utilised by the villagers for cooking, bathing, heating their houses and curing ailments. The pools and thermal areas ranged between steam emissions, warm water, hot water and hot mud. The main cooking pool was large and of extremely clear steaming water which descends down a pipe for some 50m before opening out into a space of unknown size and depth. Another spring emitted clouds of sulphurous steam in which sufferers of asthma, colds, flu, catarrh or sinus problems were recommended to stand. There were two pools of bubbling mud further away in the village, one incongruously next to the Anglican church. There was a sign next to a gate into a fenced-off area of thermal springs that warned of the thin crust overlying presumably either hot mud or, more worryingly, deep, hot pools. There was also a look-out point from which two geysers (pronounced guy-sers) could be viewed: the Pohutu, and the Prince of Wales, named for the three plumes. These geysers used to erupt to a great height on a regular timetable every ninety minutes but, we were told, since the eruption of Mount Etna some four years previously, the regular spurts ceased, evidence of a connection through the plate margins between Africa and Europe, across Turkey and Iran, down through Java and across to the plate margin between Australia and the Pacific Ocean.

The Taupo Volcanic Zone, extending from White Island 50km north of the coast from Whakatame, south through Rotorua and Taupo to Mounts Ruapehu and Tongariro, is a result of the coupling between the two plates being stronger in the south around Wellington, diminishing northwards. As a result of this it appears that the oblique subduction between two areas of continental crust has been transformed into a more conservative margin. In the south, where the coupling is strongest, the deep faulting results in severe earthquakes. In the north the East Cape is being pulled outward, increasing the distance between East Cape and the Coromandel by between 8 and 10mm a year, and forming a back-arc basin. This crustal extension is what has given rise, within the last 2 million years, to the Taupo Volcanic zone where the crust is just 8 to 10km thick and heat flow through the surface thirteen times as high as normal. Earthquakes in this zone originate within the top 6km of the crust, possibly because beyond this depth the crust is not brittle enough due to its high temperature.

In the Rotorua museum I bought a copy of *Rocked and Ruptured* by Jefley J. Aitken, a very informative book about geological faults in New Zealand with excellent colour plates, and I spent a

relaxing hour sitting in the sun overlooking the gardens outside the museum with a bottle of beer, reading. Whilst strolling around the town in the evening light I spotted Henessey's Irish bar, and could not resist a Guinness. The atmosphere of an Irish bar coupled with the relaxed New Zealand hospitality proved to be most convivial.

The next day I headed south for Taupo, the first stop on the way to Wellington and South Island.

Taupo is a neatly laid out, clean and modern town, with the main road running between the lake and the town. After negotiating a 10 foot cliff I realised I was standing on the sandy shore of a lake within the crater of the volcano that 22000 years ago exploded in what is thought to have been the largest eruption in recent times. The hole that the lake occupies was actually created by the Oruanui eruption 26500 years ago, which buried most of the area of central North Island under 200m of ignimbrite.

The water was clear and clean, lapping gently onto a black sandy beach littered with pebbles of pumice and lava (Figure 7). The sand was whiter nearer the water's edge. Looking back at the cliff face the layering of the volcanic deposits were visible in a succession progressing upwards from cobbles getting progressively finer to a coarse and poorly cemented sand containing small purple, red, black and brown stones. Above this was a layer of black coarse sand with large quartz crystals, a layer of pebbles, another layer of coarse black sand, a layer of fine pebbles, and finally a conglomerate of pumice pebbles in a sticky white clay with pink staining. Taupo erupted largely rhyolite and these deposits reflect this.

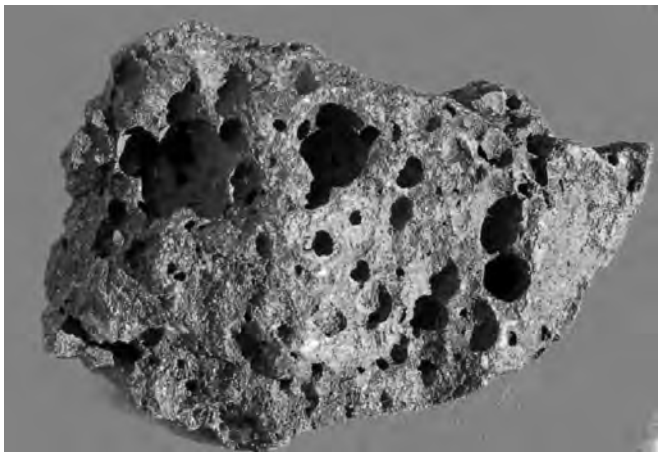


Figure 7 Rhyolite lava from the shores of lake Taupo.

The view across the lake in the early morning sunshine was quite lovely with the water as still as a mirror upon which floated some ducks (Figure 8). The lake was large, Taupo being situated at the end of a broad inlet. Inland there were high mountainous hills half cloaked in cloud disguising their full height and shape. This was Tauhara, a dacite dome with a height of 3569 feet.

Leaving Taupo at the north shore of the lake, I drove down the eastern side. The road turned away from the lake after several miles and climbed up a little through some cliffs into the Waitahanui tribal area of the Taupo forest, returning to the lake shore after about ten miles of beautiful forest road. The road then hugged the lake on one side beside cliffs of pyroclastic deposits, pumice and clay, with some rock outcrops on the other. One of the local fishermen who went out on the lake regularly said bubbles of gas were often seen rising from a large split in the Horomatangi

Figure 8. Peace and calm of Lake Taupo.

reef in the centre of the lake, with steam sometimes seen rising off the surface in the same spot. The lake is apparently very deep, and I was given the impression of a very real closeness to a potential eruption, more so than at Rotorua which had far more activity visible. Taupo last erupted around about 200 AD. This eruption covered something like 20 times the area covered by the famous Mount St Helens eruption of 1980, ejecting about 100km^3 of material.

The road left Lake Taupo behind; I was on 'The Desert Road' and soon entered the Tongariro National Park. Here the vegetation is sparse, the surrounding landscape wide, extensive and rolling. The whole area lent a general air of desolate loneliness, similar to, but more extreme than, Salisbury Plain. Away to the right were the high snow-covered peaks of Tongariro (6458ft), Ngaurohoe (7515ft) and Ruapehu (9175ft), all three of them andesite volcanoes that are still considered active, and all three with their tops wreathed in moving clouds. They certainly presented a majestic backdrop to the landscape the road was curling through, dipping down into troughs and back up onto the top. Either side of the road the banks showed the rocks and deposits which were a strong yellow-brown with occasional black bands. They had an appearance similar to the bedding seen in dune sandstones. This is ignimbrite, the bedding arising from the various flows that had covered the area, and the black bands are carbonised trees caught in the hot volcanic deposits. The different layers were eroding and weathering at different rates giving rise to shapely banks and cliffs. This landscape extended for miles and miles, covered principally with a low growth of heather, bracken and grass, with low trees and tree ferns alongside the road and in sheltered dips. Signs alerted to the danger of flash floods and also to beware of military exercises each side of the road. I even saw one sign warning of live ammunition.

There were also high cloud-covered mountains away to the left, the Kaimanawa Mountains, succeeded southwards by the Ruahine and Tararua Ranges.

Gradually the landscape became greener, more hillocky (Figure 9) and, having passed along State Highway 1 to Palmerston North, the coastline approached to the west. The landscape to the east became more hilly and also more built up. The road became hemmed between high cliffs and hills to one side and the ocean to the other, with for some while a lovely view of Kapiti island, which is a lump of Permo-Triassic sedimentary rock, like the Kaimanawa range was away to the north. The island is also apparently edged to seaward with a strip of chlorite schist.

Figure 9. Youthful hills south of the Desert Road approaching Palmerston North.

Now I was well amongst the massive faults of the Wellington area, but experienced no hint of earth movement. The first impression of Wellington, the 'city of shakes', was that of a small, modern and white city hugging the high ground on the edge of the sea. Several large and active faults underlie this area – the Wairarapa fault ruptured in 1855 causing a magnitude 8+ earthquake. This fault is to the east of Cape Turakirae about 10 miles from the city. The Wellington fault runs right through the centre of the city and last ruptured between 350 and 500 years ago.

Although I was told that the one-way system was murder to drive in, to a UK driver the traffic seemed very light and the manners of other drivers good.

I arose bright and early the next morning, and made my way to the ferry departure point from where I could look out across Wellington harbour to the point from where the ferry would come.

The ferry sailed across the harbour, docking at 9:00. Incredibly all the vehicles were off the ferry by ten past, so we left spot on time. The harbour water was clear and blue-green though the day was grey and overcast but still warm.

The good ship Arahura backed out of the dock, turned, and made her way across the harbour, presenting us with a wonderful view of Wellington's busy and active waterfront and the rusty tramp steamers and coasters tied up alongside.

We made our way across the harbour, across the top of Evans Bay and around Point Halswell. Evans Bay is a coastal indentation to the southern side of the harbour, matched by Lyall Bay on the other side of a stretch of sand dunes, the two bays arising through coastal erosion along the line of one of the large, active and parallel faults this area is crossed by, being the northward extension of the Marlborough Sounds fault complex which arose through complex crustal tension associated with the plate margin as it leaves the northern end of South Island. The rocks here are upper Triassic sandstone and mudstone sequences of the Rakaia terrane of the Torlesse supergroup.

The Torlesse rocks get their name from the Torlesse Range, in which Mount Torlesse was named after the man who first climbed it, and comprise most of the eastern side of South Island, and are basically greywackes that were derived originally from the erosion, from the Permian through to early Cretaceous times, of that part of the Gondwana continent that later became north-eastern Australia. The western side of South Island is, interestingly, composed of ancient rocks that comprise the remains of that Gondwana basement. The Torlesse rocks occur in North Island too, but are covered by largely Tertiary deposits. The rocks of the Rakaia terrane are higher in quartz and feldspar than the other Torlesse rocks.

We were now pointing toward Cook Strait, the stretch of water between North and South Island.

After a half-hour's sailing from Wellington we passed between Pencarrow Head and Palmer Head out into Cook Strait, where we then turned west for South Island, 22km away. We then turned North West around Sinclair Head, but unfortunately visibility was poor and we were unable to see South Island. There was a good enough view of the North Island coastline, however, and several pods of dolphins, some eight or ten in each, came quite close.

The Cook Strait is comprised of several marine features. To the north is the Narrows Basin which is up to 350m deep. This basin is bounded to the south by the Terawhiti Sill which stretches across the strait due west from Wellington and over which the water is about 200m deep. South of this sill is the Cook Strait Canyon, and closer in to North Island the Nicholson and Wairarapa Canyons, all of which join to meet the Hikurangi Trough, the southern seabed expression of the subduction trench between the Pacific and Australian plates. This curves in towards the land between North and South Islands, and descends to a depth of over 1000m.

The recently discovered Boo Boo fault in Cook Strait gets its name from Boo Boo Stream at Cape Campbell in Marlborough. This is a 70km long fault running east to west across the southern end of Cook Strait. It is thought to be as active and as significant as the Wellington Fault, having a slip rate of 10 to 12mm a year, which combined with the length of the active fault is estimated to cause magnitude 7.2 to 7.6 earthquakes when it ruptures. However, being so isolated it does not represent a significant hazard.

The ferry's course squeezes past the top end of the Nicholson canyon and heads north-east over the Terawhiti Sill and south-west corner of the Narrows Basin towards South Island.

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Author

Based in the south-west of England, I was previously a farm manager and then IT consultant and am halfway through an OU Earth Sciences degree. Currently taking time out in New Zealand, where the geology is making a deep impression, whilst trying to find out how to make the best use of kayaking, diving, caving and paragliding in geological studies. I return to UK in early 2006 to continue my degree.

Geology of El Cusuco National Park, Honduras

Dr Olwen Williams, Department of Ecology, Open University

Introduction

Between June and September 2005, I was the medical officer to Operation Wallacea's rain forest camp in Honduras. OpWall's main functions are to carry out biological surveys and monitoring of reef and rain forest biodiversity, to make the case for conservation and to seek grants (www.opwall.com). Much of the funding comes from the school and university students who participate in the expedition and gain a better understanding of the aims and methods of biological surveying. My role as a medic was the coordination of medical services over six different camp sites, keeping stocks of medicines and equipment, treating whatever came my way and hoping that nobody was bitten by a fer de lance – one of the deadliest snakes in the world. Intravenous fluids in a campsite, suturing a wound in an outdoor restaurant, dealing with a Honduran road traffic accident (a collision between a horse and a man carrying his bicycle) and accompanying sick patients to the local hospital were all part of the routine. While the expedition had scientists of many kinds, nobody apart from myself was interested in the geology.

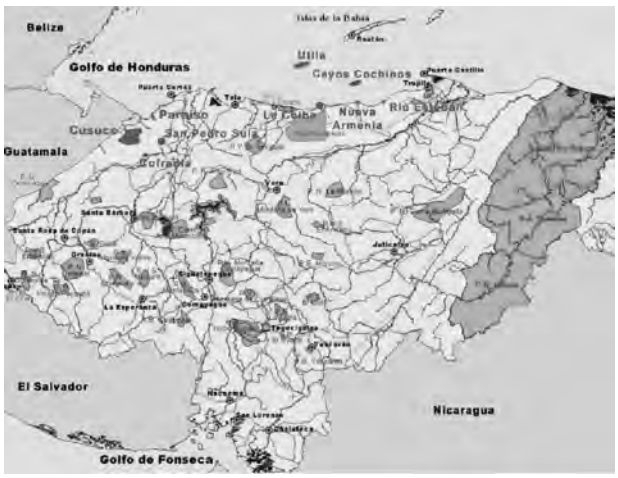

Figure 1. Map of Honduras (from Operation Wallacea Research Programme 2006-07).

Honduras is one of the poorest of the countries of Central America, mountainous, relatively undeveloped and unexploited (Figure 1). El Cusuco National Park was set up in 1987, but the initial funding for the park has expired and the number of guards greatly reduced. This, together with population pressures, means that there is increasing encroachment into the core zone of the park by hunters and farmers. It is hoped that OpWall's reports will be the stimulus for new funding from the UN and encourage the growth of ecotourism.

The geology of Honduras has been described in broad terms (Weyl 1980), but due to difficulty of access, there is very little detailed work. In the 1996 survey of the park (Evaluación Ecológica Rápida del Parque National El Cusuco 1996), note was made of metamorphic rocks, thought to have been derived from the metamorphosis of granite and also of "large amounts of black and white mica".

Much of the park was difficult to access and for the whereabouts of waterfalls on the various draining rivers, I relied on the local knowledge of the guides. My colleagues also caught my enthusiasm and supplied rock specimens and photographs from outside my home range.

Geomorphology

El Cusuco National Park lies close to the border with Guatemala, in the Merendon Mountains (Cordillera de Merendon) which form part of the northern cordilleras (Figure 1). These run roughly SE to NW and form the boundary of the water catchment of the rivers Camelecón and Motagua. The access to the park is a 20km dirt road, with steep drops into the valleys as the road winds around the mountain. The central area of the park rises to an elevation of 2240m (Cerro Jilinco) and consists of rounded peaks and steep sided valleys. Drainage of the core zone is to the Rio de Cusuco (east), Rio de Naco (south), Quebrada de Cantiles (west) and Quebrada de Jilinco (north). These rivers all have waterfalls at an elevation of about 1450 to 1500m. In addition, the river Cusuco has a lower waterfall near to Buenos Aires, in the buffer zone of the park, at about 1300m. Following Hurricane Mitch, in 1998, there were several landslides within the park, including one on the Jilinco river which is about 15km in length and 2-3 km wide.

Geology

The road between Cofradia (altitude 140m) and Buenos Aires Village (1300m) climbed through dark, metamorphic volcanic ash sediments (metasediments) (Plate 4a) which were poorly consolidated and which became brecciated and uptilted towards the mountains. Between Buenos Aires and El Cusuco National Park Base Camp (1450m), the rocks were much harder – mainly schist (Plate 4b), with some quartz. Throughout the climb, there was a very steep drop-off into the valleys.

Within the park, wherever bedrock was exposed in the rivers at altitudes over 1450m, it was a pale, medium-grained granite (Plate 4c) with maximum crystal size of about 0.8cm. Pebbles and boulders of this granite were present in the rivers, but in addition, there were pebbles and boulders of much darker, metamorphic rock at all levels. At the waterfall on the river Cusuco at La Cascada (1450m), the face of the waterfall showed a contact zone between granite and gneiss (Plate 4d), while below the waterfalls, bedrock was metamorphic rock (Plate 4e). This led me to the conclusion that the core of the mountain consisted of a granite batholith, which had intruded the volcanic ash sediments and produced an overlying layer of contact metamorphosis. Direct observation at La Cascada suggested that the gneiss contact auriole was about 10-40m in thickness. The lower waterfall, near to Buenos Aires at 1300m, was entirely within the metamorphic zone.

At this stage, I was not clear to what extent the granite core was exposed. Direct observation of bedrock is difficult in rain forest, apart from in the river beds. Climbing towards the peaks became increasingly arduous as the vegetation became dwarfed and the understory denser (botanically, this is the dwarf forest or Bosque Enano). Towards the summits, there was no rock to be seen and ascent was over a thick layer of vegetation. However, the landslide at 1900m provided the best clues. Here, I found boulders which showed a clear contact between the granite and the meta-

morphic rocks and this was also seen in the stream bed at this site (Plate 4f). At the same time, the slumped material consisted of a mixture of soil and broken rock, mainly metamorphic and varying from soft easily broken volcanic ash sediments through schist to gneiss, and also some weathered granite. This indicated that, apart from in the river beds above 1450m altitude, the overlying ash and metamorphic contact layers were largely intact (Figure 2).

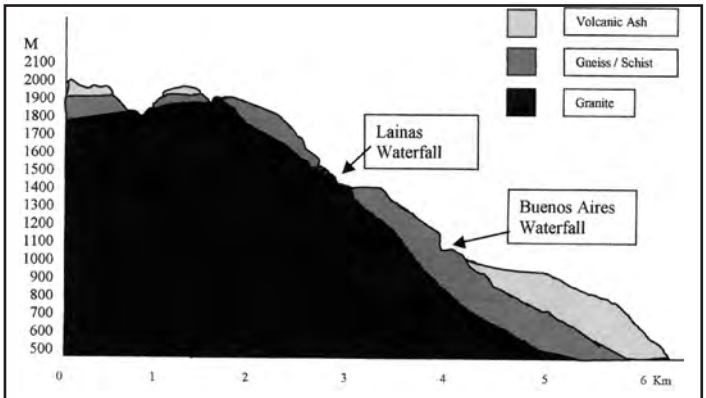

Figure 2. Schematic Cross-section through El Cusuco National Park.

In addition to the granite and metamorphic rocks, I found some pebbles of lava, basalt and quartz.

Discussion

Central America has two large units which are totally different from each other. To the north (Guatemala, W. Honduras, El Salvador and W. Nicaragua) there is continental-derived crust with Palaeozoic or older metamorphic rocks, overlain by upper Palaeozoic, Mesozoic and Tertiary sediments. Deformation occurred in the middle Permian and also around the KT boundary. Large masses of ignimbrite were extruded in the Tertiary. In the south, there is Cretaceous oceanic-derived crust overlaid by thick Tertiary marine sediments and volcanics (Weyl 1980). Central America is also tectonically active, especially Honduras, where there is a three-way junction between the N. American, Caribbean and Cocos Plates. Geothermal activity can be found in several areas of Honduras (Eppler 1986). Although Honduras itself does not have any active volcanoes, these are found all along the Pacific coast of adjoining Central America in Guatemala, El Salvador, Nicaragua and Costa Rica, as a result of the subduction of the Cocos Plate under the Caribbean Plate.

The Merendon mountains lie in the northern group of sierras, which are characterised by Palaeozoic granitic intrusions, highly metamorphic rocks and local Palaeozoic and Mesozoic sediments (Weyl 1980). The ranges are separated by faults and grabens, e.g. the Camelecón valley in Honduras marks the position of the fault between the Caribbean and N. American plates. Here, vertical faulting up to 2km has occurred, together with horizontal movement of 10km over several million years (Weyl 1980).

The core of the El Cusuco National Park consists of a granite batholith (Figure 2), above which is a zone where the intruded volcanic ash sediments have been converted by contact metamorphism to gneiss and schist. I estimate the gneiss zone to be about 10-40m thick and the overall depth of metamorphosis up to 1km. More distantly, the surrounding volcanic ash sediments have been up-tilted and brecciated.

The hard metamorphic rocks seen in the stream beds are derived from the contact zone, along with eroded granite boulders and pebbles. Although the granite is exposed in the stream beds over 1450m, available evidence suggests that the unexposed areas of the mountains have not been eroded back to the granite – the landslide shows a considerable amount of poorly metamorphosed metasediments, as well as gneiss and schist. It is likely that the waterfalls mark a surface transition from granite to metamorphic rock at around 1450m. A lower waterfall (1300m) and the steep drop-off into the valleys mark the transition from hard to softer metamorphic rocks (Figure 3).

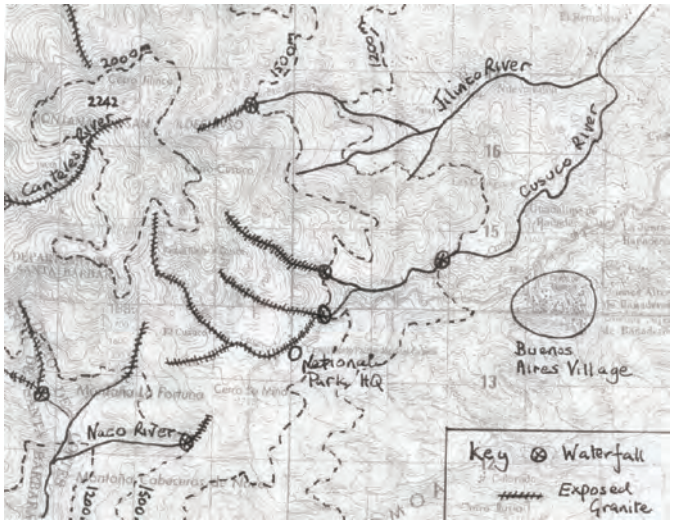

Figure 3. Geological Map of El Cusuco National Park, Honduras.

Conclusions

El Cusuco National Park lies in the higher part of the Merendon Mountains. These consist of a Palaeozoic granitic intrusion into volcanic ash sediments. The granite is only exposed in the river beds above 1450m. Elsewhere, there is evidence of a continuing cover of contact gneiss and schist with overlying layers of less well metamorphosed sediments and soil. Where these persist, there is considerable potential for landslides, especially in the steep river valleys. At about 1450m, each of the draining rivers has a waterfall, marking the lateral surface extent of the granite intrusion (also approximating the edge of the core zone of the park). A lower waterfall and the steep valley drop-offs mark the transition from hard to softer metamorphic rocks, towards the edge of the park buffer zone.

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Acknowledgements

Thanks to Operation Wallacea for the opportunity to study this area and to all colleagues and friends who provided observations and specimens from parts of the park I was unable to visit. Figure 1 is reproduced with kind permission of Operation Wallacea.

Assessment of earthquake-triggered tsunami hazards in the Straits of Messina and eastern Sicily, Italy

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Abstract

The aim of this paper is to assess earthquake-triggered tsunami hazards in the Messina Straits and eastern Sicily, Italy. A tsunami is a series of water waves generated by the sudden displacement of the sea floor resulting in a displacement of the sea surface from its initial equipotential equilibrium level. This pressure gradient generates gravity waves, the height of which increases with decreasing water depth. The main tectonic feature in eastern Sicily is an active normal fault belt that runs along the Calabrian arc through the Messina Straits and along the eastern coast of Sicily. The distribution of crustal earthquakes suggests a strong relationship between seismic activity and extensional structure growth. Several large tsunamis have been recorded in historical times including the 1693 and 1908 tsunamis that struck eastern Sicily and the Messina Straits causing severe damage and many victims. Studying tsunami hazards starts with gathering and interpreting data in order to compile catalogues of all known tsunamis. Statistical analyses are applied to seismic databases in order to estimate frequencies of earthquake occurrences. Using relationships linking earthquake and tsunami parameters, those frequencies are converted into frequencies of tsunami occurrences. Deterministic approaches involve scenarios, which are based on an event believed to be representative of what is expected to occur. Estimated return periods of earthquake-triggered tsunamis capable of producing coastal wave heights exceeding a given threshold are computed and maps are produced. Tsunami hazards are a serious threat in eastern Sicily and the Messina Straits, and the risk is high. However, risk mitigation is currently limited to a tsunami warning system installed in Augusta. Inundation maps are being produced, but there is no evidence of tsunami educational programmes, specific building practices or coastal structures against tsunamis. Further research is needed and it is urgent to produce and publish inundation maps.

Introduction

Tsunami is a Japanese word which means harbour (tsun) wave (ami) because such waves often develop as resonant phenomena in harbours following offshore earthquakes (Bryant 2001). A tsunami is a series of water waves generated by the sudden displacement of the sea floor or by an impact at the surface (Dawson *et al*. 2004). Most tsunamis are triggered by earthquakes, but landslides, volcanic eruptions or meteorite impacts may also cause them. Tsunamis are a major hazard in the Mediterranean, especially in Italy and Greece where several large destructive tsunamis have occurred in historical times. According to a recent tsunami catalogue (Tinti *et al.* 2004c), eastern Sicily and the Straits of Messina are the regions where the most destructive tsunamis have occurred in Italy (Figure 3). In 1693, a tsunami produced damage and flooding in the towns of Messina, Catania and Augusta in eastern Sicily (Tinti & Maramai 1999). The most destructive tsunami in Italy occurred in 1908 in the Straits of Messina (Dawson *et al.* 2004).

Most tsunamis in eastern Sicily and the Straits of Messina are triggered by earthquakes. This region is characterised by a high seismicity level and therefore a high seismic risk. Moreover, most tsunamis are generated locally and waves may reach the coastlines within 5 to 10 minutes of the earthquake (Maramai & Tinti 1996). If tsunamis like the 1908 or 1683 events were to occur today, communities along the eastern coast of Sicily and the Straits of Messina would be at high risk because there would be little time to evacuate them. In addition, the level of coastal occupation and development has increased steadily in recent years resulting in a higher vulnerability of coastal zones. Therefore, the effects of future tsunamis with the same magnitude as past events is expected to be far more damaging.

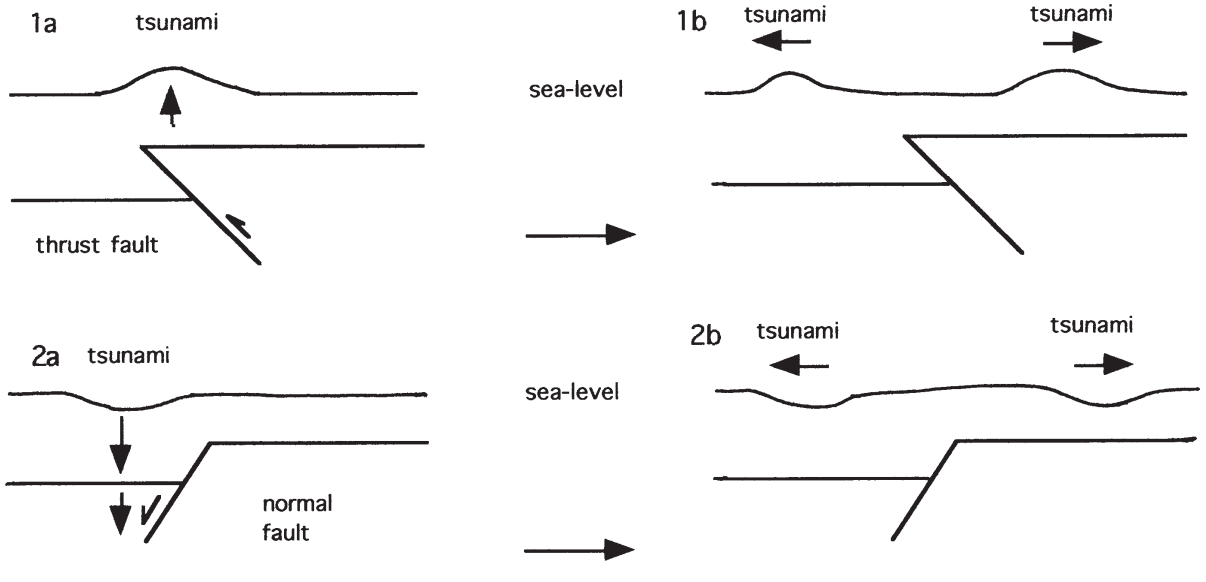

Figure 1. Earthquake-triggered tsunami generation (© Ghier 2005).

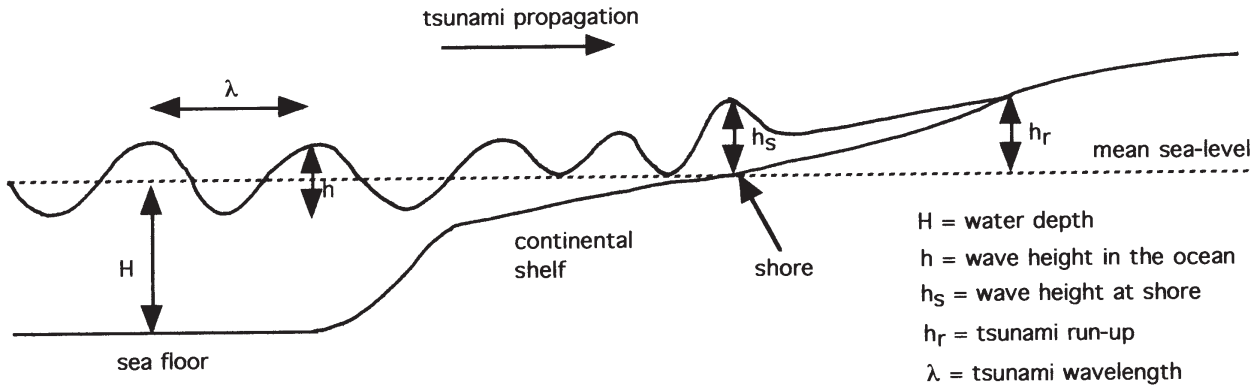

Figure 2. Wave and tsunami terminology (adapted from Bryant 2001 fig. 2.2).

Earthquake-triggered tsunamis

Origins of earthquake-triggered tsunamis

An earthquake-triggered tsunami is a series of water waves generated by the sudden displacement of the sea floor. Tsunami generation is due to sea floor uplift or subsidence, which causes a compression or expansion front, respectively, and produces an elevation or depression of the sea surface when the front reaches the surface (Figure 1). The pressure wave results in a displacement of the sea surface from its initial equipotential equilibrium level (Tinti *et al*. 2004a). The hydrostatic pressure gradient generates gravity waves which radiate from the source area.

Features of tsunamis

Tsunamis in the deep ocean are described by sinusoidal waves (Brown *et al*. 1999). However, tsunami waves become steeper across the continental shelf and non-linear models are used. Wave and tsunami terminology is shown in Figure 2.

Tsunamis travel as shallow-water waves because they propagate in water depth H which is small compared with tsunami wavelength λ (i.e. $H/\lambda<0.05$). Tsunami wave speed is $c=\sqrt{(gH)}$ where g is the acceleration due to gravity (Brown *et al*. 1999). The deeper the water, the faster the wave (Table 1).

Table 1. Ocean depth, tsunami wave speed and height (based on formulae in Bryant 2001).

Ocean depth (m)	Tsunami wave speed (km per hour)	Tsunami wave height (m)
4 000 (deep ocean water)	710	1
100 (continental shelf)	110	2.5
10 (very shallow water)	35	4.5

Tsunami periods are between 30s and 12 hours (Wells 1997). Tsunami wavelengths are very large (several hundreds of kilometres) making them difficult to detect in the open ocean (Bryant 2001). For a typical tsunami (period 10^3s), the wavelength in deep ocean ocean water is approximately 200km, resulting in a sea surface slope of one in several thousand (Knauss 1996). Earthquake-triggered tsunamis tend to have longer wavelengths, longer periods and a larger source area than those generated by landslides (Prager 2000).

The energy acquired during tsunami formation sets the entire water column in motion (Prager 2000). As orbital velocities do not decrease significantly with depth, the energy contained in the entire water column is huge. Tsunamis conserve their initial energy in the open ocean because energy dissipation due to internal and bottom friction is negligible (Tinti *et al*. 2004a). Furthermore, the rate at which waves lose energy is inversely proportional to their wavelength (Prager 2000). Therefore, tsunamis contain much energy, move at high speeds, and can travel great distances with little energy loss.

As a tsunami moves into shallow water, it slows and steepens. The wave's energy is transferred from the ocean to the land (Prager 2000). The tsunami's wavelength and speed decrease, and its height increases (Table 1). The bottom part of the wave slows, whereas the top continues at the same speed, which makes the wave 'bunch up'. The higher the wave, the greater the energy dissipated when it breaks. Tsunamis are particularly erosive due to higher velocity and greater pressure on the seabed compared to storm waves (Bryant 2001).

The maximum limit of landward incursion can be estimated with $x_{max}=[0.06(h_s)^{1.33}]/m^2$ (Bryant 2001), where h_s the wave height at shore (Figure 2) and m the Manning's number (Table 2).

Estimating run-ups is difficult because they depend on many factors including coastal steepness, original wave height, shore configuration, resonance, diffraction, refraction and reflection (Bryant 2001).

Table 2. Manning's numbers (based on Bryant 2001)

Manning's numbers	Typical areas
0.0015	mud flats; pastures; very smooth topography
0.03	developed land; areas covered in buildings
0.07	densely forested landscape

Tectonics and tsunamis in eastern Sicily

As earthquake-triggered tsunamis are caused by the sudden displacement of the sea floor, areas which are tectonically active are

Table 3. Length and slip rate of fault segments along the Siculo-Calabrian rift zone and major earthquakes in the last 1000 years (adapted from Monaco and Tortorici 2000 Table 2)

Area	Fault segment	Length (km)	Vertical slip rate (mm per year)	Earthquake magnitude (M_S)	Year
Southern Calabria	Cittanova	35	0.7	7.1	1783
	S. Eufemia	18	0.7	5.7	1894
	Scilla	≈ 20	≥ 0.7	6.3	1783
	Reggio Calabria	25	0.6	7.1	1908
Eastern Sicily	Messina-Taormina	≈ 30	≥ 1.0	?	?
	Piedimonte	15	1.1-1.2	4.1	1922
	S. Alfio-Acireale	≈ 20	1.5-2.0	4.0-6.3	1865-1989
	Western offshore	≈ 45	≥ 1.2	7.4	1693
	Avola	20	0.7	6.1	1693
	Rosolini-Pozzallo	≈ 20	0.5	4.6	1896

particularly prone to tsunamis. Eastern Sicily and south-western Calabria are the most seismically active areas of the central Mediterranean (Monaco & Tortorici 2005).

Tectonic setting of eastern Sicily

Tectonic activity in eastern Sicily results from the collision between the African plate margin and the crustal unit of the Calabrian arc, which belongs to the Eurasian plate (Piatanesi & Tinti 1998). The main tectonic feature in Calabria and Sicily is an active normal fault belt that runs along the Calabrian arc through the Straits of Messina and along the eastern coast of Sicily as far as the Hyblaean Plateau (Figure 3). According to Monaco and Tortorici (2000), this fault belt, which results from a rift zone related to an ESE-WNW extension with slip rates of 0.5-2mm per year, is about 370km long and is composed of several fault segments ranging from 15 to 45km (Table 3). In eastern Sicily, the fault belt mostly runs off-shore (Figure 3).

Why the area is prone to earthquake-triggered tsunamis

The distribution of crustal earthquakes suggests a strong relationship between seismic activity and extensional structure growth because the epicentres of these earthquakes form a seismic belt, which runs along the Tyrrhenian side of Calabria and southward along the Ionian coast of Sicily and the Hyblean Plateau (Monaco & Tortorici 2000). Combining geological, geomorphological and structural evidence, and data on the historical seismicity of the area, some fault segments have been identified as the surface expression of active structures generating earthquakes (Tortorici *et al*. 1995).

According to Monaco and Tortorici (2000), the different fault segments of the Siculo-Calabrian rift are responsible for the large earthquakes that occurred in the region. These events were caused by slippage along 30-40km-long normal fault segments mainly located offshore. The 1693 earthquake in eastern Sicily was

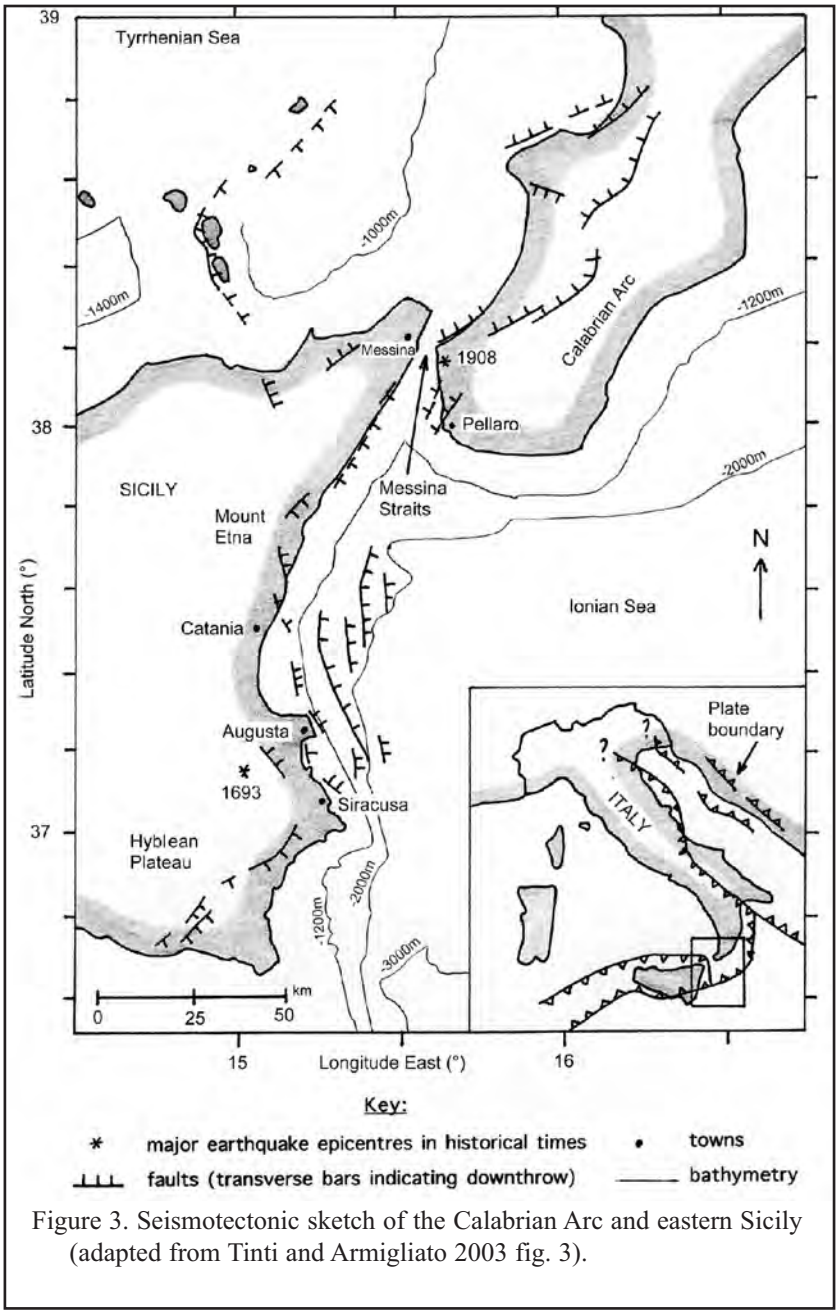

Figure 3. Seismotectonic sketch of the Calabrian Arc and eastern Sicily (adapted from Tinti and Armigliato 2003 fig. 3).

Table 4. Known earthquake-triggered tsunamis in eastern Sicily and the Straits of Messina (based on Dawson *et al.* 2004; Soloviev *et al.* 2000; Tinti *et al.* 2004d).

Year	Site of manifestation of tsunami	Description (1)	Earthquake magnitude (2)	Tsunami intensity (3)
362 (possibly 365)	Sicily	The sea severely flooded the dry land.	?	5
963	Sicily	The sea flooded dry grounds.	?	5 - 6
1169	Eastern Sicily	Inundation and destruction in Messina.	6.8	4 - 5
1172	Sicily	The sea became dry after an earthquake.	?	?
1329	Eastern Sicily	Boats pulled up on the shore were carried away into the sea.	?	3
1562	Reggio di Calabria	The cape submerged, then vanished completely, and the sea appeared at its place.	?	4
1613	Region of Messina	The stormy sea battered the land. Inundation in Naso.	5.6	4
1649	Straits of Messina	Almost all ships in Messina harbour were beaten against each other and sunk.	?	5
1693	Eastern Sicily	A tsunami was observed on the shore from Messina to Siracusa (see section 4.2).	6.8	4
1699 (possibly 1693)	Eastern Sicily, Catania	The sea near Catania receded from the coast by more than 2000 metres.	?	4
1783	Straits of Messina	5 Feb: Sea reported to have receded along the Calabrian coastline. At least 3 inundations at intervals of about 10 minutes. Messina was flooded. 6 Feb: At least 1500 victims because people went to the beach to escape the earthquake. Also 7 Feb; 28 March.	6.3 (5 Feb)	5 - 6
1818	Eastern Sicily, Catania	The sea receded several metres from the coast, then quickly returned to its usual level.	6.2	3
1894	Straits of Messina	Ship run aground in Reggio di Calabria.	7.0	4
1907	Messina and Calabria	The sea penetrated deep onto dry land for 30-80m over a distance of 10-20km between Cape Bruzzano and the River Careri, and then it receded farther than its usual limit.	5.9	3
1908	Straits of Messina	Most destructive tsunami in Italy (see section 4.3).	7.0	6

(1) Dawson *et al.* 2004; Soloviev *et al.* 2000; Tinti *et al.* 2004d
(2) Surface-wave magnitude
(3) Tsunami intensity on Sieberg-Ambraseys scale

generated by the slipping of a normal fault extending about 12km offshore from Catania to Siracusa. The 1783 earthquake in southern Calabria was triggered by displacement along a fault located along the coast from Villa S. Giovanni to Palmi. The 1908 Messina earthquake has been related to a rupture along the west-facing Reggio fault that partially extends offshore south of Reggio Calabria (Monaco & Tortorici 2005). Therefore, eastern Sicily and the Straits of Messina are seismically active areas characterised by normal faults that, since they mainly occur offshore, also generate large destructive tsunamis (Monaco & Tortorici 2005).

Historical earthquake-triggered tsunamis in eastern Sicily

Historical accounts of tsunamis are important because they provide information on the frequency and magnitude of past events.

Recorded earthquake-triggered tsunamis in the area

Catalogues of Italian tsunamis have been recently compiled (Tinti & Maramai 1999; Soloviev *et al*. 2000; Tinti *et al*. 2004d). Characteristics of known earthquake-triggered tsunamis in eastern Sicily and the Straits of Messina over the last 2000 years are included in Table 4.

The 1693 tsunami in eastern Sicily

One of the most severe earthquake-triggered tsunamis in Sicily occurred on 11 January 1693 producing severe damage in eastern Sicily and the Straits of Messina (Piatanesi & Tinti 1998). Historical sources report that the sea retreated three times followed by a violent return, coastal flooding and three major waves in Taormina, Mascali, Catania, Augusta and Siracusa (Dawson *et al*. 2004).

The town of Augusta was the most severely affected, with waves as high as 15m (Tinti *et al*. 2001). The initial withdrawal drained the harbour completely, causing severe damage to the ships, especially two large vessels coming from Malta. Sailors saw the water under the kneels of their ships disappear. Then the ships were suddenly thrown towards the coast when the water returned (Soloviev *et al*. 2000). The sea submerged the district close to the port as far as the convent of Saint Dominic about 1km inland and killed many people who, alerted by the big foreshock of two days before, were camping near the pier (Piatanesi & Tinti 1998). In Catania, the sea inundated the town penetrating Piazza San Filippo (now Piazza San Mazzini) about 500m inland and flooding farmsteads and buildings in the suburbs of the city (Soloviev *et al*. 2000). In Mascali, the sea receded from the coast and subsequently flooded the dry land over more than a mile (Soloviev *et al*. 2000).

The 1908 tsunami in the Straits of Messina

The 7.0 magnitude earthquake which occurred in the Straits of Messina on 28 December 1908 produced a violent tsunami that caused severe damage and many victims (Dawson *et al*. 2004). The tsunami was observed as far as Malta, more than 400km to the south-east, and Naples, more than 350km north of the source (Tinti & Armigliato 2003).

Data are abundant and comparable with recent events (Tinti & Armigliato 2003). The first observed movement was the retreat of the sea, followed by coastal flooding with at least three large waves (Dawson *et al*. 2004). Tsunami run-ups (Figure 2), which were particularly high (Table 5), were observed to decrease with increasing distance from the epicentre but this was obscured by wave resonance in the Straits of Messina (Dawson *et al*. 2004).

Table 5. Maximum run-ups (data from Tinti 1983)

Towns	Maximum run-ups (m)
S. Alessio (Sicily)	11.7
Giardini Naxos (Sicily)	9.5
Lazarro (Calabria)	10.6
Reggio Calabria (Calabria)	9.7

In Messina, harbour quays were destroyed, walls collapsed and several boats were damaged and carried on shore (Dawson *et al*. 2004). The communication cables through the Straits were broken (Tinti 1983). Eyewitnesses reported a very loud noise before the tsunami (Soloviev *et al*. 2000). According to some sources, the tsunami began almost immediately after the earthquake, but according to other data, there was about 10 minutes between the earthquake and the tsunami (Soloviev *et al*. 2000).

Earthquake-triggered tsunami hazards and risk in eastern Sicily

Definitions of hazard and risk

A hazard is a potentially dangerous phenomenon affecting a particular location (S390 2004). A geohazard results from adverse combinations of geological and/or atmospheric processes and/or ground conditions involving or affecting human activity. The event is unexpected and/or sudden, and likely to cause significant loss or harm (S390 2004). Risk results from hazard and vulnerability. It is a measure of exposure to loss, death, or injury caused by a hazard (S390 2004).

Earthquake-triggered tsunami hazards in eastern Sicily

Studying tsunami hazards starts with gathering and interpreting data in order to compile catalogues of all known tsunamis in the area. Then research based on statistical and deterministic models is carried out in order to evaluate tsunami hazards (Tinti *et al*. 2004a).

Catalogues of Italian tsunamis cover 2000 years of history (Table 4). However, these catalogues are not exhaustive because the authors could not access all the materials from historical archives. Details depend on when tsunamis occurred but catalogues are essential because they form the bases on which modelling and mathematical analysis are carried out.

Only about 300 tsunamis are known to have occurred in the Mediterranean over the past 2000 years, whereas earthquakes recorded in the last few decades reach tens of thousands (Soloviev *et al*. 2000). Therefore, tsunamis are rare events, and statistical analyses have to be applied to seismic databases instead of tsunami databases.

Statistical analyses on earthquake-triggered tsunamis in eastern Sicily have been performed by the tsunami research group from Bologna university. The main steps of the statistical procedure (Tinti *et al*. 2004b) are:

1) estimating the frequencies of tsunamigenic earthquake occurrences; converting those frequencies into probabilities of tsunami occurrences using relationships linking earthquake and tsunami parameters;

2) assessing the initial disturbance of the sea using relationships between earthquake and tsunami sizes;

3) evaluating the expected maximum tsunami height on the coast using propagation properties of tsunamis.

Estimated return periods of earthquake-triggered tsunamis capable of producing coastal wave heights exceeding a given threshold are computed and maps are produced. However, statistical approaches may be hampered by adopting relationships linking earthquakes to tsunamis, which may not be empirically well grounded (Tinti & Armigliato 2003).

Deterministic approaches are based on models which always produce the same output for a given set of data. They are based on mathematical equations which do not involve statistical or probabilistic ideas (Bronshtein *et al*. 2003). A scenario is a deterministic approach to tsunami hazards based on an event believed to be representative of what is expected to occur (Tinti & Armigliato 2003). Scenarios aim at reconstructing events as effectively as possible from historical sources and tectonics, reproducing them through numerical modelling and computing the wave effects on the coastlines, including wave energy, arrival times, wave height and currents (Soloviev *et al*. 2000). The Earth's upper crust is usually modelled by a homogeneous and perfectly elastic layer whose top is flat (Tinti & Armigliato 2003). Uncertainties in the identification of the source fault remain for the 1693 and 1908 earthquakes (Tinti & Armigliato 2003).

Table 6. Main towns in eastern Sicily and the Straits of Messina (data from Pearsall and Hanks 2003)

Towns	Inhabitants (in 2001)
Catania	306,464
Messina	236,631
Reggio di Calabria	179,384
Siracusa	121,000

Historical records and scenarios based on the 1693 and 1908 tsunamis and historical records show that inundation is the major hazard due to tsunamis in eastern Sicily. Secondary hazards include water pollution, landslide, erosion, deposition (Solway 2004).

Earthquake-triggered tsunami risk in eastern Sicily

Eastern Sicily and the Straits of Messina with several towns over 100,000 inhabitants (Table 6) form a densely populated region with a well-developed urban infrastructure, industrial settlements and large centres of tourist activity (Bonapace *et al*. 1989). Therefore, the vulnerability of the area is high.

In conclusion, tsunami risk is high in eastern Sicily and the Straits of Messina.

Description of tsunami mitigation in the area

Definition of risk mitigation and methodology

Risk mitigation is 'a term used for various measures (e.g. planning, engineering, sociological) that attempt to reduce the risk to hazards' (S390 2004). Those measures are taken independently from an emergency situation. Anti-hazard measures are not possible against tsunamis. Therefore, risk mitigation aims at reducing vulnerability. Methodology is based on a combination of various measures including land uses, specific coastal structures and building practices, warning systems, inundation and evacuation maps, and educational programmes.

Land uses, coastal structures and building practices

The redevelopment of coastal areas at risk from tsunamis can be an effective defence (Smith 2001).

Figure 4 illustrates several measures that could be included in a risk mitigation scheme. The beach and forest are used to dissipate the energy of the onshore wave whilst development and the coastal evacuation road are located above the predicted height of the 1:100 year event (Smith 2001). Densely forested landscape has a relatively high Manning's number (Table 2), which limits the landward incursion of the waves. The waterfront could be developed into a public park as in Crescent City, California, after the 1964 tsunami (Bolt 1999). There is no evidence that such redevelopment of coastal areas has been carried out in eastern Sicily.

Specially engineered structures can also offer some protection against tsunamis. Breakwaters and tsunami walls tend to weaken the tsunami waves, reducing their heights and the width of the inundation zone (Bell 2003). Figure 5 shows an offshore breakwater, an onshore tsunami wall and coastal development used as an integrated tsunami defence. These structures have been built in Japan. For example, the town of Ofunato is protected by a breakwater built across the entrance to the bay and a similar structure was built in Kamaishi to protect the local steel industry and the fishing fleet (Smith 2001). Although breakwaters do not occupy land and can provide shelter for shipping, they are expensive and interfere with tidal circulation (Smith 2001).

Tsunami modelling provides information on the interaction of the water waves and coastal structures. Tinti and Armigliato (2003) showed that the three breakwaters at the entrance of Augusta harbour reduce the impact of incoming tsunami waves. A similar

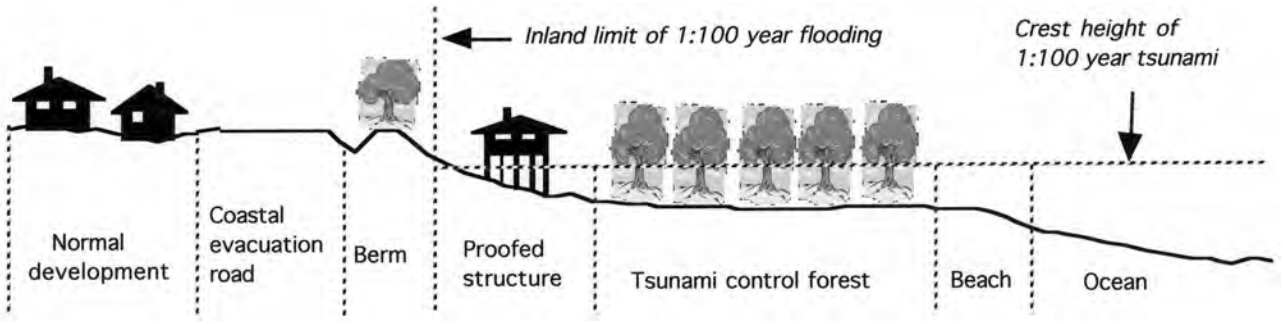

Figure 4. Coastal land use and planning designed to mitigate tsunamis (adapted from Smith 2001 fig. 6.1)

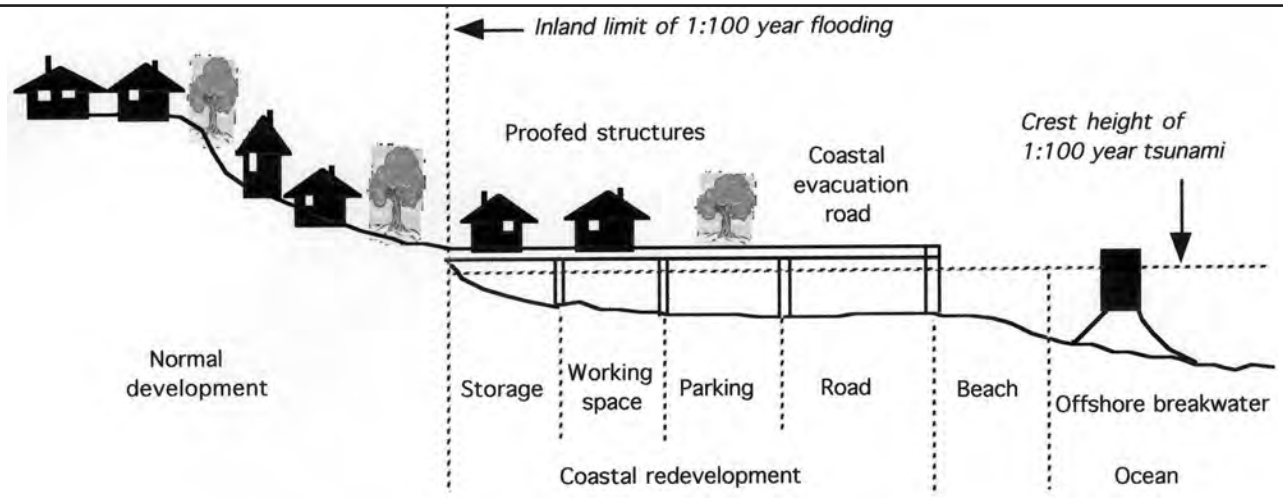

Figure 5. Tsunami engineering works (adapted from Smith 2001 fig. 6.8).

approach could be applied to other important harbours such as Catania, Messina and Reggio Calabria. However, there is no evidence that specific coastal structures against tsunamis have been built in eastern Sicily.

To minimise the effects of tsunamis, buildings can be constructed with reinforced concrete frames and elevated on reinforced concrete piles with open spaces at ground level (e.g. for car parks). The waves can then flow through the ground floor without adversely affecting the building (Bell 2003). Buildings are usually orientated at right angles to the direction of approach of the waves, that is perpendicular to the shore (Bell 2003). Homes and other buildings can be removed to higher ground and new construction prohibited in the areas of highest risk (Bell 2003). Seismic risk surveys have been carried out in eastern Sicily (Goretti & Di Pasquale 2002) but there is no evidence that any construction work in this area has taken good practices against tsunamis into account.

Tsunami warning systems

Several instruments can be used to detect the passage of tsunamis. Sensitive seismographs record waves with long-period oscillations. Pressure recorders placed on the sea floor in shallow water detect pressure variations. Buoys anchored to the sea floor are used to measure changes in the level of the sea-surface (Bell 2003).

Most existing Tsunami Warning Systems (TWSs) are inappropriate for Italy because they are designed for tsunamis which are not generated locally. A pilot tsunami warning system devised for immediate detection and early warning (at most 3-4 minutes after the event) was installed in Augusta, eastern Sicily, in 1998 (INGV 2005). This site was chosen because

1) the area is prone to earthquake-triggered tsunamis
2) the coastline has significant social, economic and environmental values,
3) facilities for installation and maintenance were available (Maramai & Tinti 1996).

This pilot TWS is based on the simultaneous acquisition and processing of seismic and sea-level signals. An automatic station processes data from a pressure gauge and a barometric unit. If anomalous variations in sea-level are detected, an alarm is transmitted to the control centre located in the Augusta seismic station. A computer processes seismic signals and emits an alarm in case of an earthquake. If both alarms match, a tsunami alarm is transmitted to the Civil Protection unit (Maramai & Tinti 1996).

Inundation and evacuation maps

Inundation maps are based on historical data and tsunami-modelling techniques. These maps can be used to educate people about tsunami risk and help emergency planning in the event of a tsunami (Prager 2000). Moreover, inundation maps are a very valuable tool for city planners to identify areas at risk (Preuss *et al*. 2001).

A group formed by researchers from the 'Istituto Nazionale di Geofisica e Vulcanologia' (INGV) and Bologna university is involved in producing a map of tsunami hazards in eastern Sicily and western Calabria (Amato & Selvaggi 2002). A detailed historical reconstruction of the coastal urbanisation in 1693 has been carried out in order to draw real inundation maps. Using up-to-date thematic territorial maps (e.g. cadastral maps, town maps, country maps), structures considered to be 'weak points' in the event of inundation have been identified (Amato & Selvaggi 2002). In addition, a study has been carried out by the Italian governmental agency 'Agenzia per la protezione dell'ambiente e per i servizi tecnici' in order to investigate the risk generated by a tsunami in the industrial area of Prioto-Augusta (APAT 2004).

Educational programmes

According to Prager (2000), the easiest and most effective tsunami countermeasure is to teach people living, working and holidaying along a shore to expect and recognise the warning signs of a tsunami. When the ground begins to shake, they should be taught to move inland and up as fast as they can. They should be reminded that it is important not to panic. Other signs such as unusual water motion including rapid retreat of the water should be taken into account. As tsunamis advance further and faster along flat surfaces, people should be taught that they should not go to the beach or waterfront to see the tsunami. There is no evidence that such educational programmes exist in Italy in spite of similar programmes for seismic and volcanic hazards (Protezione Civile 2004).

Evaluation and assessment of tsunami hazards in eastern Sicily

Assessment of earthquake-triggered tsunami hazards

Earthquake-triggered tsunami hazards in eastern Sicily and the Straits of Messina have been studied using various techniques such as catalogues, statistics and deterministic approaches (scenarios). Catalogues seem to be reasonably complete and well documented. Statistical methods are difficult to apply because of the relatively small number of tsunamis in the area. Scenarios for tsunamis have been developed only for the town of Augusta. In my opinion, the current model of the Earth's upper crust used in scenarios is not adequate in areas with high bathymetric gradients such as eastern Sicily (Figure 3). Therefore, it is questionable whether current scenarios produce representative models of tsunamis in eastern Sicily. A 3-D approach including sea-floor topography would require more powerful computers but would provide more realistic results. Moreover, no serious evaluation of secondary hazards such as water pollution, landslide, erosion and deposition has been carried out in eastern Sicily and the Straits of Messina.

Assessment of earthquake-triggered tsunami risk

Studies of past events and present-day population have shown that earthquake-triggered tsunami risk is high in eastern Sicily and the Straits of Messina. However, there is very little evidence of studies on the vulnerability of people, buildings and industrial facilities in the event of a tsunami. Some monitoring has been carried out in Augusta since 1998 but trying to 'reduce the risk' does not seem to have been seriously taken into account by the Italian government in spite of repeated alarms given by Italian researchers (Tinti & Armigliato 2003).

Evaluation of tsunami risk mitigation

According to Bernard (2001), the best tsunami mitigation is to keep people and critical facilities out of the area of flooding. The three effective steps to create a 'tsunami-resistant community' are:

1) produce tsunami inundation maps;

2) implement and maintain a tsunami awareness programme;

3) develop early warning systems.

As far as eastern Sicily and the Straits of Messina are concerned, inundation maps are in the process of being produced. However, there is no evidence that any of them have been published or distributed to the local government.

Tsunami awareness programmes do not seem to exist in spite of similar programmes for seismic and volcanic hazards. It should be possible to include tsunamis in the current programmes run by the 'Dipartimento della Protezione Civile'. Educational leaflets similar to those available for seismic and volcanic hazards could be produced and made widely available as an official source of information about hazards and risk in the region.

An early warning system has been working in Augusta since 1998. However, there is no other warning system implemented in eastern Sicily. According to Boschi *et al*. (2005), a global warning system covering the whole Mediterranean should not be too difficult to implement. It would be based on local warning units (e.g. municipality, district), regional warning units (province, region, nation), and global warning system units covering the Mediterranean. The sub-systems would require sensors to monitor sources (e.g. earthquakes) and tsunami waves, and efficient modules of data transmission and alert management. The existing broadband seismic network MEDNET currently managed by the 'Istituto Nazionale di Geofisica e Vulcanologia' (INGV) in Rome could be used. This network consists of more than 20 seismic stations covering the Mediterranean, and has demonstrated rapid and accurate earthquake location and magnitude determination. The network would have to be completed by further seismic stations and tsunami gauges.

Bernard's points 1 and 3 are in the process of being implemented in eastern Sicily and the Straits of Messina. Point 2 should not be too difficult to implement. However, because of the density and importance of the present coastal infrastructures (e.g. harbours, tourist centres, archaeological sites), it would be unrealistic for local government to prevent or limit building and occupation of the coastal environment. It would not be possible to construct large coastal barriers (e.g. breakwaters, sea walls) along significant stretches of the coastline because of the negative aesthetic impact that such structures would have on the local environment. It would also be unrealistic in terms of economic costs to reinforce every building within the tsunami flood hazard zone (Papathoma *et al*. 2003). Moreover, it should be borne in mind that local government may be reluctant to encourage costly studies and risk mitigation measures against tsunamis in a region where seismic and volcanic hazards are far greater.

Conclusion

Earthquake-triggered tsunamis represent a major hazard in eastern Sicily and the Straits of Messina with several large tsunamis recorded in historical times. The risk is high because of the recent development of the coastal area. However, risk mitigation is currently limited to a tsunami warning system installed in Augusta. Inundation maps are being produced, but there is no evidence of tsunami educational programmes, specific building practices or coastal structures against tsunamis. Detailed studies must be carried out in eastern Sicily because the likely impact of future tsunamis will be much greater than in the past. Moreover, there will be very limited time available for early warning or evacuation because the points of origin and impact sites are relatively close.

Although a recent tsunami catalogue has been compiled and a tsunami warning system has been running in Augusta since 1998, current knowledge of earthquake-triggered tsunami hazards in eastern Sicily and especially in the Straits of Messina is limited. Scenarios involving towns other than Augusta have yet to be carried out. The current model of the Earth's upper crust is not an adequate representation of the sea-floor in eastern Sicily and the Straits of Messina. A 3-D approach including sea-floor topography would provide more realistic results. Moreover, current scenarios do not seem able to produce satisfactory identification of the source fault of the 1693 and 1908 earthquakes. No pilot risk management such as that provided in the Herakleio coastal area, Crete (Papathoma *et al*. 2003), has been carried out. In addition, nearly all the studies on earthquake-triggered tsunamis in eastern Sicily and the Straits of Messina have been performed by the same group of researchers. Input from other Italian and international groups would be beneficial.

Further research is needed. Running detailed scenario simulations to estimate the effects of earthquake-triggered tsunamis would assist in developing knowledge and understanding of earthquake-

triggered tsunami hazards on the eastern coast of Sicily. Catania, Messina, Reggio di Calabria and Siracusa are obvious towns to be studied because of their large population (Table 6). More in-depth analysis of Augusta harbour is needed. Moreover, the development of a 3-D model of the Earth's upper crust and its inclusion in scenarios would provide more realistic results in evaluating earthquake-triggered tsunami hazards in eastern Sicily and the Straits of Messina. Given the potentiality of the hazard in a densely populated region, it would be prudent to ensure constant monitoring of movement along active faults. It is urgent to produce and publish inundation maps of the eastern coast of Sicily because most risk mitigation measures are based on these maps. A modern risk analysis assessing tsunami vulnerability, such as the one carried out in Herakleio, Crete (Papathoma *et al*. 2003) should be conducted and educational leaflets similar to those available for seismic and volcanic hazards should be produced and made widely available as an official source of information about current hazards and potential risk in the area. If the region were to be included in the global warning system covering the whole Mediterranean, it would help get funding and promote more research as eastern Sicily and the Straits of Messina are the regions where the most destructive tsunamis have ever occurred in Italy.

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Book review

Granite Landscapes of the World by Piotr Migon, 2006, Oxford, 284 pages, £95 hardback, ISBN 0199273685.

This is the second volume in a new Oxford series, "Geomorphological Landscapes of the World." The author is Professor of Geography at the University of Wroclaw, but has written the work himself in impeccable English. We probably all know some granite landscapes, but have not realised their diversity; showing this is the primary aim and very comprehensively it is done. The secondary aim is to provide an explanation for this variety, challenging because "our understanding of granite geomorphology is still incomplete". But much relevant work has been done in the past 20 years, making it timely to supplement the last standard reference book, Twidale's Granite Landscapes (1982).

The approach is not regional but systematic, a sensible choice given the varied coverage of granite regions in the literature; also because similar landscapes appear in different parts of the world. So there is a brief but comprehensive first chapter on the geology of granite, followed by nearly 60 very meaty pages on granite weathering. A chapter on "Boulders, Tors, and Inselbergs" follows, headed by a note on the problems of terminology of these typical granite forms. Another long chapter is on "Slope Development in Granite Terrains", an area now much better understood. Sensibly he has separate chapters on "Granite Coasts" and "Cold-Climate Granite Landscapes". Another very meaty and well organised chapter follows on "Geological Controls in the Evolution of Granite Areas": the various tectonic settings, lithological variation, discontinuities, and "hierarchy of geological controls".

This last is a very interesting short section explaining how "different structural and lithological properties control landforms of different sizes, and the same rock characteristics may be of the utmost importance for some landforms and largely irrelevant for others. For example, to explain the present-day altitude of granite masses in relation to the country rock, the tectonic setting, uplift rates, and related long-term denudation rates need to be considered first, whereas such information matters little if patterns of mass movements on rock slopes over decadal time scales are to be deciphered. For the latter, the characteristics of jointing patterns will be crucial." A consideration relevant not only to granite landscapes.

After bringing together much of what he has said in "Typology of Granite Landscapes", the author ends with a short but fascinating chapter on "Granite Landscapes Transformed" by humans. There is a very long bibliography, and a great many photographs – many of them disappointingly poorly reproduced.

Philip Clark, BSc (Hons) Open

The Human Impact on the Natural Environment: Past, Present and Future by Andrew Goudie, 2006, Blackwell Publishing, 357pp (paperback) £24.99, ISBN 1-4051-2704-X.

This book by Andrew Goudie immediately caught my attention as the front cover has a picture of eucalyptus trees dying from salinity in Western Australia which happened to be the subject of my website project for U316! The book is split into two parts. Part 1: The Past and Present, and Part 2: The Future.

Part 1 has an Introduction and then chapters on the Human Impact on Vegetation, on Soil, on Waters, on Climate and on the Atmosphere and the Human Influence on Animals and Human Agency in Geomorphology.

Part 2, after the Introduction, has chapters on The Future of Coastal Environments, Hydrological Impacts, The Cryosphere and then Drylands followed by a Conclusion. At the end is found a good glossary, references and index.

This book has stood the test of time as it was first published nearly a quarter of a century ago and has been periodically updated and revised. Although it has 357 pages it is crammed full of diagrams, tables, graphs, maps and examples from all over the world. Although these are all in black and white, almost every page has a diagram or photograph on it that clearly supports the text.

The chapters if read sequentially build on one another from the early hunter gatherers moving on to people as farmers and cultivators and their gradual impact on the Earth as the global population grew and urbanization started to take over. It covers all aspects of human influence from the use of fire, clearance of land, domestication of animals, deliberate modification of waters, pollution, industrialisation and the effects on the environment. The future covers global climate change and examines changes in sea levels, weather patterns, ice sheets, salinity and concludes with questions such as 'Are changes reversible?'

However the book is also so clearly laid out that it can be used for reference. When I first picked it up I dipped in and out of the chapters on geomorphology, climate and hydrological impacts before settling down to read the whole book.

It is a fascinating read full of facts and figures, but with a very easy narrative style not often found in a volume of this nature. It is book that would appeal to the interested amateur and would also make a useful addition to any earth sciences bookshelf and give background reading in many of the OU Earth sciences and environment courses.

Eileen Fraser BSc(Hons)(Open) DipEarthSci(Open) FGS

Teaching Rocks to KS 1 & 2

Alan Bates

I have been invited to write this article by the Journal Editor having produced a somewhat more racy account for the West Midlands Branch Newsletter. I wish to start with a disclaimer: I am not a qualified teacher and I have no reason to believe I will ever become one. I hold the teaching profession in the highest respect; not least because my wife has taught every age group from "rising 5s" to final year A-level. This article is not intended to be the definitive, "This is how geology should be taught at age 7/8." Even to pretend I could (or should) write such an article would be ridiculous and bordering on the offensive. It presents (warts and all) the approach I took to a 2-hour afternoon class of lively 7/8 year olds in the hopes that it might be of interest to some and may even encourage a few to try the same.

As do many others, my grandson's school has an active Parent, Teachers and Friends group and encourages involvement in the school. I started to think (a rare and dangerous moment) and decided I could get involved by talking to his class about rocks. Since my grandson had previously taken the occasional rock and fossil into school, his teacher knew my interests in this area. When I tentatively offered, the question was not, "What experience have you?" or, "Are you qualified?" or, "Have you taught before?" but, "WHEN?" and "How long do you want?" Lesson 1, do not even hint unless you mean it!

It was at this stage that I started to ask myself the questions, "Have I gone completely bonkers?" and "What do I know about teaching Key Stage 1 & 2?"

The teacher pointed me to the school standards website and showed me what is covered at Key Stage 1 & 2:

http://www.standards.dfes.gov.uk/schemes2/science/sci3d/?view=get

But she added, in effect, "But don't worry about being tied down to the curriculum, just do what you want!" She also told me that she was so confident that she intended to walk out and spend the afternoon in the staff room relaxing with a cup of coffee. I was pretty sure that this was not going to happen but it was around this time that panic set in!

I have had some experience of "teaching" in a non-classroom situation and I have always believed that if you know exactly what you are trying to achieve, the whole process becomes, if not easier, then at least controllable. So my first stage was to think what I was trying to achieve. Could I sum up in a single sentence what I wanted to do?

I could have chosen, "To cover the Key Stage 1 & 2 curriculum point by point." Laudable, and maybe even what a professional teacher would do – and more power to their elbows! But with my lack of experience and formal training, would it work for me and for the class that would have to suffer from my mistakes? Unlikely. For me it was time to think what I really wanted to get across. Rocks fascinate me. They can look so similar but they can each tell such an interesting story. Could I try to get across some of the "Joy of Rocks" that I feel? Could I show how rocks give a window into an ancient world? The answer I came up with was, "Why not!" If I could cover a few points from the curriculum in the process then so much the better.

My objective, therefore, became to show that rocks are a window into the past and tell us about the history of the world. Where possible, I would draw in points from the National Curriculum but the main theme would be to make rocks and studying rocks interesting and exciting.

Having decided the broad direction, I could now look at how I could do this. What were the resources available to me?

I have learnt from experience that OU students (and staff) are enormously helpful and so I sent out an S.O.S. (Save an Open Student) on the OUSA Geological website. I said I was completely bonkers but I had offered to do this thing and could anyone offer any thoughts? The immediate responses told me that, yes, I was indeed completely bonkers (which at least confirmed my own diagnosis but did not seem to move me forwards). Then the useful stuff started to come in with hints like:

"Keep it local"

"Build on what they already know"

"Try joining the Primary Section of the Earth Science Teachers Association (ESTA)"

Then others came out of the closet and declared that while I was completely bonkers, I was not alone. They also had done the same and they not only survived but also enjoyed the experience and went back year after year. "And here is how I go about it."

And it was not just the students. One of the tutors from S283 (I suspect he is a closet geologist just pretending to be an astronomer) told me how he started by passing round a piece of rock and then telling them it was a piece of dinosaur poo (coprolite in a distinguished Journal). Great impact!! The fact that I lacked the required lump of dinosaur poo was a disadvantage but it opened up other ideas: "What about…?", "Could I try…?"

Just a note of warning. Someone else did the same thing of passing round some dinosaur poo but the Head Teacher was so disgusted that they were not invited to do the planned follow-up. Another lesson. Keep in close contact with the class teacher (and if necessary, the Head) so there will be no surprises and there is a meeting of minds on what you are trying to achieve.

I ended up with over 20 replies along with some further messages to my mailbox, including some from real teachers. One student offered me a selection of gem minerals: diamonds, sapphires, rubies, emeralds and more unusual things like Apache Tears, complete with the legend behind them. Now, I would have to admit that they would not, perhaps, appeal to Victoria or David Beckham, but to me they were like pure gold and showed again how OU students go above and beyond anything one might expect or even hope for (thanks Frances, you know who you are!). On a more mundane level (but no less helpful and well meant) I was offered a range of rock samples from Northern Ireland and the Scottish Isles (again gratefully accepted). With all this real and 'virtual' support, I was able to move out of panic mode into something a bit more constructive.

I thought more about the resources I had available. The classroom had a computerised white board, a microscope that was linked to

the white board, computers etc. Marvellous stuff if you know how to use it! I am old enough to realise that such things can be a turn-off unless they work perfectly. Bells, whistles and the proverbial dog and pony show are not my forte so I passed on that.

Going back to my objective: I wanted the children to get some of the joy and pleasure in looking at rocks. What better, therefore, to have them look at, examine, fondle, hold, scratch, enjoy ... ROCKS, not computers. Nothing against computers but I did not get a fascination with rocks and fossils looking at a computer screen.

I worked out that the resources I wanted were rocks: big rocks, small rocks, hard rocks, soft rocks, metamorphic rocks, igneous rocks, sedimentary rocks, beautiful rocks, plain rocks. Anything as long as it was a rock! The school had a collection: all unlabelled and unidentified but many of them capable of being used. Those that I was unsure about I took with me to a meeting of the OUGS Executive at Birmingham University and got the experts to identify them (use all the resources at your disposal). The table at the front groaned with rocks.

I have a few rocks of my own, collected over the years (ask my wife sometime what "a few" means, if you dare!). In addition, I have good relations with Bardon Aggregates (Wenlock limestone quarry on Wenlock Edge) and with Hanson Aggregates (dolerite and coal measures on Clee Hill, Shropshire). So, on the basis that they could only say, "No", and they were probably too polite to do so, I asked for enough pieces of rock for each child to have a piece of dolerite (blue-black, sparkling dhustone) to take home and plenty of limestone for each table.

Be especially careful with the choice of rocks if the children are going to handle them. While the chances of poisoning the children are low, nobody would thank you for passing round samples of native asbestos or arsenic! In any case the children should wash their hands after the lesson.

At the start the class teacher went through the Health and Safety aspects (she also alerted the class to any particular hazards just before they met them). She got the children to work out what the hazards might be. Rocks could be heavy and some might have sharp edges or they could be dusty. So, only handle the rocks over the tables, don't drop them on tender toes and no fighting over the rocks! By watching the teacher I was able to see how she worked with the children: lots of interaction, let them come up with ideas and gently steer them if necessary. Another lesson: discover and follow the normal class etiquette: the children will feel comfortable with it and will respond better.

I started by being dressed in my geologising mode. Safety boots, hard hat, anorak, rucksack. I said I was a geologist and this was what I normally wore when I went out looking at rocks. I asked them what I was wearing and why I needed it. Then I took off the anorak and I had a hammer in my belt and a handlens on a lanyard. They spotted them and worked out why they were needed. The handlens is because the most important thing is for a geologist to use their eyes and look for clues about the rocks you find. What are rocks? They are the building blocks of the Earth. A rock is like a word that goes together with other rocks/words to produce the history of the Earth. The rocks tell us that Stourport (local area) was very different in the past.

When I asked them where the nearest rocks were a few talked about the red Permo/Triassic sandstone around Stourport (not in those terms – they were not that good!). One of them was sharp enough to tell me the nearest rocks were just under our feet – clever boy!

Figure 1. Alan in full flow at the start of the session.

The main part of the lesson was taken up with them working in their normal groups (class etiquette again). Each table had a seed tray containing rock samples, wrapped in newspaper and numbered. The rocks I chose were local (except for one) and all of them would have seen some of them before. Living in Worcestershire with South Shropshire little more than a stone's throw away, I was spoilt for choice. The ones I decided on were:

1 Dolerite from Clee Hill - a piece for each child to take home.
2 Tephra from an unknown volcano, possibly Italy?
3 Silurian limestone from Wenlock Edge.
4 Coral fossils from the Wenlock limestone.
5 Pieces of roofing slate.
6 Permian desert sandstone from a few miles away.
7 Useful ores and minerals (different for each table such as galena & barytes from the Shelve inlier, coal & ironstone from Clee Hill).

Each of these was unwrapped one by one by the children and they had a chance to look at them, feel them, scratch them with a 2p coin (which I provided, one per table—I got them all back too!). The teacher circulated to nip in the bud any problems. There was also a classroom assistant who used to teach at Secondary level who sat with one table. Only one child had to leave and spent the rest of the lesson in silence in year 4, the ultimate deterrent. One by one, when they had all looked at them and tested them I got them to tell me about: the colour, how hard it was, could they scratch it or did the rock scratch the coin etc. (But not for samples 2, 4 and 7.) After they had looked at the Wenlock limestone, I went round with a tray and a dropper of hydrochloric acid and got each table in turn to put their limestone onto a tray (no holes). I put the acid on the rock and took it away safely immediately after it had fizzed.

For the dolerite, I introduced the idea of an igneous rock (brief summary on A3 wall chart) and extended it to the tephra. Likewise sedimentary rocks for the limestone and metamorphic rocks for the slate. The previous week they had done some cooking and I used the analogy of baking a cake and how with the same ingredients the end product was different depending on how

Figure 2. Testing for hardness - a 'hands on' approach

long it was cooked and how hot it got (tie things in to what they already knew and was fresh in their minds). All of them recognized the pieces of slate and that gave them the reassurance that I was not going over their heads.

I explained what each piece of rock added to the story of Stourport and the immediate area through the ages. How we were in a shallow coral sea near the equator, how the climate changed to produce luxurious forests and coal swamps. How it changed again as we drifted north to turn the whole area into a desert like the Sahara. The same desert sandstone has been used locally to make caves in which people lived until a few decades ago and all of them would have seen the rocks and some would have been in the rock houses. Every rock was allowed to tell its own part of the story with as much as possible gleaned from the children themselves.

Most of the rocks allowed me to talk about how we can use rocks. For example, a path was laid recently at the school and I asked the workmen for a piece of the dolerite they used. That led onto dolerite being used in foundations for paths and roads. Dolerite from Clee Hill has also been re-melted and spun into rock wool for insulation, some of which was used in their school. Limestone is one of the most important raw materials for industry and I explained how much limestone went into making a house or a car. Snailbeach mine in Shropshire used to be the most productive single lead mine in the country while Ironbridge and Clee Hill both had their own industrial revolutions based on coal, limestone, sandstone, clay and ironstone. All the time they had their own pieces of rock in front of them while I explained how important they were.

All good things come to an end and I had to do a quick summary before the end of school. The children were asked to wash their hands (just to be sure) and a quick look around showed that everything except the dolerite had been left behind (for me to clear up). Probably giving them the dolerite at the start led to less walking-off with samples than might have happened. However, if you do not want to loose something, it might be better not to take it or take a lump so big that it cannot easily be removed!

Two comments were priceless:

"Please, Miss, can we have a rock club?" and

"My rock [dolerite] has got JEWELS in it!!"

Afterwards I asked the teacher for feedback and made sure she was happy with what and how I had covered things.

Was the effort worthwhile? You bet!

Am I going to do it again? Absolutely!!

The author

Alan Bates retired from a career as an industrial chemist in the electricity industry, ending up as the Station Chemist at Sizewell B power station. He has always had an interest in geology, sparked by spending long hours as a child at the South Kensington Museums in London. Retirement has given him the opportunity to study geology at the OU and he is about half way towards an OU degree to add to his BSc. in Chemistry obtained more years ago than he chooses to admit.

Book review

Microfossils by Howard A Armstrong & Martin D Brasier, Second Edition, 2005, Blackwell Publishing, 296pp, £32.99, (paperback) ISBN 0-63205278-1.

Increased knowledge and understanding of microfossils has led to this second edition of a successful textbook introducing the study of these organisms. Like the first edition, this textbook will be of interest and readily understood by amateurs as well as professionals and students.

Throughout the book the line drawings and diagrams are excellent, the use of boxes to illustrate in more detail, important points raised in the text, I thought very useful.

The book is divided into four parts plus an appendix. A list of references used is given at the end of each chapter.

PART 1, Chapters 1-5: In these chapters the authors' give detailed explanations of what is meant by a microfossil, why these organisms are useful in the study of biostratigraphy, palaeoecology and what they can tell us about environmental and sedimentation processes. Also their increasing importance as thermal indicators in hydrocarbon exploration.

PART 2, Chapters 6-8: The emergence of life and evolution from single cell to more complex organisms, as evidenced from the fossil record, is introduced in these chapters. Special attention is given to the microfossil record, especially the importance of these organisms in the study of older sediments and the Cambrian explosion of biota.

PART 3, Chapters 9-13 and PART 4, Chapters 14-21 are devoted to detailed descriptions of (part 3) organic-walled and (part 4) inorganic-walled organisms. In these chapters, together with the line drawings and diagrams, photomicrographs and electronmicrographs are also occasionally used.

The morphology, life cycle, habitat and geological distribution of each species is described in great detail, together with the type of study for which each organism is best suited.

These chapters will enable ready identification of the majority of known microfossils.

Hints at the end of each chapter are given as to where specimens of each species of microfossil may be found, and indeed in some instances where extant specimens are found. Reference is also made as to the appropriate chapter in the appendix for preparation of that particular species.

THE APPENDIX: This gives detailed instructions on the preparation of the microfossil being studied. Not all the methods require a laboratory, all need at least a x20 microscope and some need electron microscopes.

At £32.99 this is a reasonably priced textbook and a must for anyone interested in the study of microfossils.

Muriel Wright BA (Hons) Open

Some observations on tectonic plate movement

Martin Beaney

Introduction

As a Mechanical Engineer who spent a whole career working on the stress analysis of structures, I cannot resist looking at mechanical problems and putting numbers to them to try and describe what is happening. Tectonic plate movement is a mechanics problem and, true to form, when I first came across it, the temptation to look more closely at its dynamics was irresistible.

Taking a very simplistic view of the problem immediately showed that a force far larger than the accepted driving forces is at work, and, as an additional bonus, it also explained why subduction zones are arc shaped.

Applying these ideas to the collision zone between the Indian and Asiatic plates shows that, not only is the collision zone unusual as it appears that a continental plate is being subducted, but also gives a method for estimating the time taken for the Tibetan Plateau to rise.

The Problem

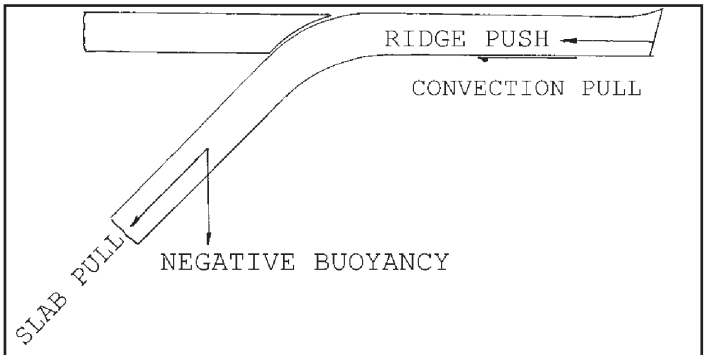

Figure 1. Accepted plate forces.

The accepted view of the forces that drive tectonic plates is that there are three possibilities, shown in Figure 1. The first of these is ridge push, which is a function of the elevation of the mid-ocean ridge. Secondly, convection currents in the mantle could provide a force to the underside of oceanic plates driving them away from the constructive boundary. The third possible force is the slab-pull force which arises because the subducting plate is cooler and, hence, denser than the surrounding mantle into which it is sinking. This negative buoyancy pulls the slab downwards and hence provides the slab-pull force shown in Figure 1. England & Wortel (1980) give the maximum values of ridge-push and slab-pull per unit width as $3*10^{12}$N/m and $3*10^{13}$N/m respectively. Kearey & Vine (2003), suggest that convection currents have a negligible effect.

I have difficulty with the view that slab-pull is the dominant force. As shown in Figure 1, the direction of the negative buoyancy is vertically downwards. If this is the major force then, after bending, the slab would have to be subducted in the direction of this force, i.e. vertically. None of the descending slabs appear to sink vertically, thus slab-pull cannot be the predominant force.

An analysis of the problem

The crust and lithosphere form a very thin rigid membrane on the surface of the Earth. This membrane is under the considerable compressive stress of ρgx, where ρ is the density of the membrane, g is the gravitational constant and x is the distance below the Earth's surface. If the membrane thickness is t, then the average stress through its depth is $\rho gt/2$. This compressed membrane floats on the asthenosphere.

At a subduction zone, the edges of the plate are not in contact and across the zone no compressive stress can be sustained. In other words, a subduction zone is a hole in the membrane. If this were a hole in a balloon or submarine, catastrophic failure would occur. Fortunately the plates of the Earth's surface are well supported by the asthenosphere. However the only force between the plates in the direction of motion of the subducting plate is the friction force shown in Figure 2.

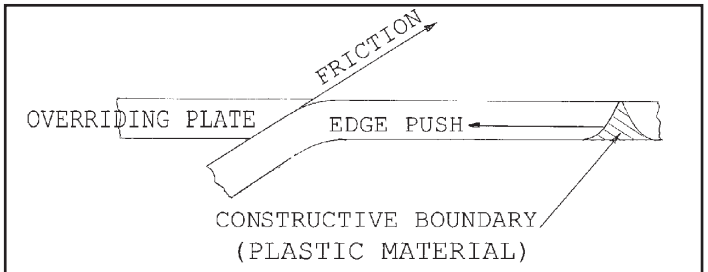

Figure 2. Major plate forces.

The particular feature of a constructive boundary is that if the plates are drawn or forced apart, the edge-push force in Figure 2 is maintained, for the following reason. If the plates move apart, the level of the plastic material tends to drop, reducing its pressure. This drop in pressure causes more plastic material to flow into the gap, restoring the pressure and hence the force across the boundary. There is a maximum rate at which this can happen, as the movement must be slow enough for the plastic material to flow into the gap to restore equilibrium. The pressure in the gap is similar to that in the rest of the plates, i.e. $\rho gt/2$. Thus this stress applies a force of $\rho gt^2/2$ per unit length of the constructive boundary. Using the values of ρ = 3300kg/m^3, t = 85km, and g = 9.8m/s^2, gives the force, $F_E \sim 10^{14}$N/m. Since this is an order of magnitude greater than the slab-pull force, the dominant force on the plate is the edge-push force of 10^{14}N/m, due to the pressure at the constructive boundary.

This mechanism for moving the plates is entirely consistent with the positive correlation between plate circumference connected to downgoing slab and slab velocity as given by Kearey and Vine (2003 fig. 11.13). The difference being that they attribute the correlation to slab-pull force, whereas in my view it is related to the difference between the forces applied at the constructive and destructive plate edges. Clearly since there is a rough equality in length between constructive and destructive boundaries either mechanism would give this positive correlation.

A similar conclusion can be drawn regarding the overriding plate. The edge force applied to the overriding plate at a subduction zone is of similar magnitude to that on the subducting plate, i.e. it is negligible compared to the edge-push applied at constructive boundaries. Thus overriding plates will also be forced away from

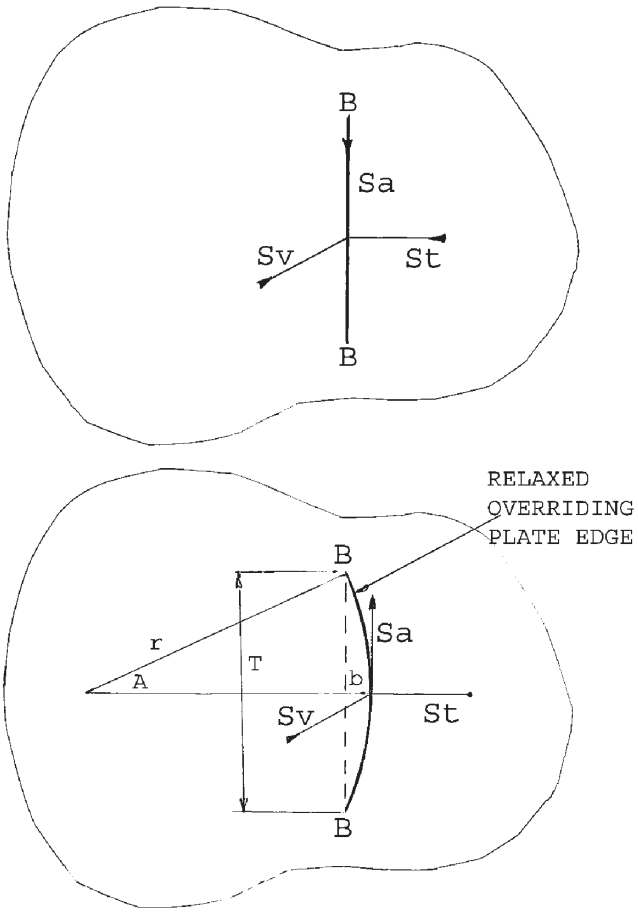

Figure 3. Overriding plate stresses.

constructive boundaries towards subduction zones. For example, the South American Plate is being driven by the edge force at the Mid-Atlantic Ridge towards the Nazca Plate subduction zone along the western seaboard of South America.

The lack of edge force at the subductive boundary must have another consequence with regard to the overriding plate. If, as shown in Figure 3, a subduction zone is formed by breaking the plate at the line BB, then when the subduction zone BB has formed, the stress St must be zero. Thus there is a release of a stress of ρgt/2 across this line. With this stress removed, the edge of the plate will clearly relax outwards as shown in Figure 3. A finite element analysis of the overriding plate would provide both deformation and stress in the plate. However, in the absence of such an analysis, it can be speculated that the final state of stress on the plate edge is probably as shown in Figure 3, with Sv=-ρgx, Sa=ρgx, and St=0 . Whilst the vertical stress, Sv and St must be as shown, an assumption has to be made about the stress, Sa, along the subduction zone. Firstly, to hold the plate together it must be tensile. Secondly, the assumption is made that it will have the same magnitude as the vertical gravitational stress from which it arises.

It is shown in the Appendix that this change in stress along the subduction zone leads to a ratio of bow b, to trench length T of 0.06 which is similar to that of the island arcs.

Trench Depth

The assumption is made that material failure is related to the maximum shear stress. The maximum shear stress at depth x on the edge of the overriding plate is [Sa-(-Sv)]/2, which, from above, has the value ρgx. This stress rises linearly with depth. It seems quite likely that when this stress reaches some failure level the subducting plate will shear off the lower surface of the overriding plate, forming the base of the subducting trench at this depth. Trench depth is, therefore, directly related to material strength and an estimation of the failure stress of the ocean crust material could be obtained from a knowledge of trench depth. Clearly a proper analysis could produce useful material properties. It is interesting to note that a similar stress regime controls the height of the Tibetan Plateau. The edges of the plateau are unsupported, and will start to spread when stresses become too high. This occurs when the plateau reaches a height of about 3.5km, which is a similar order of magnitude to the depth of subduction trenches.

Collision Between Indian and Asiatic Plates

The Indian plate has been colliding with the Asian Plate for some 50Ma. The question is what is driving the plate? From above, it is clear that as soon as the plates came into edge-to-edge contact, a considerable stress and hence, force would build up between them. Initially this force is likely to be small, but there is no reason to suppose that its final value is much smaller than the edge force of $\rho gt^2/2$. This being the case, when the plates collided a retarding force of this magnitude would have been applied to the edge of the Indian plate. Now force equals mass times acceleration, thus: $\rho gt^2/2 = m*acc$, where m is the mass of a unit width of plate. Thus, $10^{14} \sim 3500*10^3*85*10^3*3300$, where the distance from the constructive boundary to the collision zone is 3500km, plate thickness and density are taken as above. This gives the deceleration as $0.1 m/s^2$. This would bring the plate to a halt within a few seconds, never mind 40Ma. The only conclusion I can draw from this is that, like the view taken by Lyon-Caen & Molnar (1983) the Indian plate is being subducted under the Asian plate. This would obviously agree with their analysis of the gravitational anomaly and would also be consistent with the raising of the Tibetan Plateau.

Assuming that the Tibetan plateau was raised as the Indian plate was forced under the Asiatic plate then an accurate timing for the lifting of the Tibetan plateau should be calculable, as follows: If the distance from the original subduction zone to the northern edge of the Tibetan plateau was, say, 1500km and the average speed of the Indian plate was, say, 60mm/year, then it would have taken 25Ma to raise the plateau.

Conclusions

Taking a different view of the forces which control plate motion not only isolates the dominant force acting on the plates, but also gives a reason why subduction zones are arc shaped. Moreover, it is suggested that the depth of subduction zone trenches are directly related to the strength of the crust material and could, hence, provide a source of material properties.

Applying these ideas to the Indian-Asiatic collision zone suggests that the Indian plate must be subducting beneath the Asiatic plate. If this is the case, then the time it takes to raise the Tibetan plateau is easily calculable.

Appendix

Before the subduction zone is formed, the stresses on line BB are as shown in Figure 3 to be Sv = Sa = St, and have the common value of -ρgx, where x is the depth below the surface. The ‘locked

in' strain is in the direction along BB, therefore:

$$e = 1/E(- \rho gx + \mu\rho gx + \mu\rho gx) \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where μ is Poisson's ratio for the rock, and E is Young's Modulus.

The final stresses on BB after subduction starts, are, from above, $Sv = - \rho gx$,

$Sa = \rho gx$, and $St = 0$, and the strain is, therefore:

$$e = 1/E(\rho gx + \mu\rho gx + 0) \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The difference between (2) and (1) gives the strain along BB due to the formation of the subduction zone as:

$$\Delta e = 1/E(2\rho gx - \mu\rho gx) \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

From Figure 3, the difference in length of the arc BB, and the line BB is 2rA-T

Hence the strain is:

$(2rA-T)/T = \Delta e = 1/E(2\rho gx - \mu\rho gx)$

$$\text{But } T = 2r\sin A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4)$$

Therefore:

$A/\sin A - 1 = 1/E(2\rho gx - \mu\rho gx)$

as before taking ρ as 3300kg/m^3, g = 9.8m/s^2, x as the reasonable depth of say 4km, and E = 20GN/m^2 gives:

$A/\sin A - 1 = 1.1*10^{-2}$

Thus A = 0.26rad

Hence the ratio of arc bulge to trench length is:

$$b/T = (r - r\cos A)T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Combining (4) and (5) gives:

$b/T = (1-\cos A)/2\sin A = 0.065$

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Book reviews

Geomorphology and River Management – applications of the River Styles framework by Brierley, G.J., and Fryirs, K, 2005, Blackwell Publishing, 398pp, (paperback) £39.95, ISBN 1 4051 1516 5

Brierley and Fryirs are the co-developers of the River Styles framework which is part of a short course at Macquarie University, Australia. This book is the companion to that course. The sleeve notes say this is essential reading for a range of practitioners including students, technical officers, consultants and academics. I think practitioners is the key word here.

The book is set out in three sections: The geo-ecological basis of river management; Geomorphic considerations for river management; and, the River Styles framework.

Sections one and two are well set out with an introduction, and each subsection follows a logical progression. There are plenty of well drawn and labelled diagrams that help explain the concepts. This provides a good basic understanding of how and why rivers change spatially and temporally. There is a very good reference section (further reading) included.

The River Styles framework provides a hierarchical approach that enables a student to describe and explain within-catchment distribution of physical river forms and processes. It also considers human modifications and realistic restoration and recovery options. This section is based on field work examples, and assumes the reader will have access to the data sources cited, and to software to allow the framework to be followed. These may be available in a conventional university and therefore this section is more applicable to part of a taught fluvial systems course. This is a disadvantage for distance learners who may not have access to or the technical skills required to follow this section.

However, putting that disadvantage aside, there is a lot of interesting material and the case studies do provide good examples of how to assess a river's character and behaviour. If you are interested in rivers and in particular how and why they change then this is a good read.

I would refer to this book at university level 2 as part of an Integrated Catchment Management or Fluvial Systems module (after all I am interested in rivers…) – but at just under £40, it is rather expensive and its fit with current OU earth-science courses is tenuous.

Penny Widdison, PhD, OU Tutor.

Fluvial Sedimentology VII, Blum M D, Narriott S B, Laclair, S F (eds), 2005, Blackwell, 589pp, £75.00 (paperback) ISBN 1405126515. This is "Special publication no.35" of the International Association of Sedimentologists.A preface explains that this book is a compilation of 29 papers given at the 7th International Conference on Fluvial Sedimentology, held in Lincoln, Nebraska, USA, during August 2001. The preface also includes a summary of general and special interest sessions, field trips and contributors to the four-day conference.

The book is divided into four broad sections entitled "Fluvial processes & forms" (12 papers); Experimental & numerical model making (2); Quaternary fluvial systems (6); Pre-Quaternary fluvial systems (9). The case studies are from world-wide locations; British regions cited include the Old Red Sandstone at Manorbier, Pembrokeshire; the River Coquet at Holystone, Northumberland; Allt Dubhaig river in Scotland; the East Pennine Basin at Silkstone Rock. At least nine of the papers seem to be mainly lab-based (modelling) and with reference to other studies.

There are plenty of illustrations, both monochrome and colour, including diagrams, maps, photographs and photomicrographs, 3D-models, borehole data, cross-sections, stratigraphic logs, graphs and sketches.Each paper concludes with a comprehensive bibliography, and there is an excellent index. However, the addition of a glossary would help the general reader.

I found several papers extremely interesting, because I have done work on rivers outside the OU. The field-work papers were generally more interesting than the lab-based ones, although some of the latter included references to field locations. The book would provide valuable information for somebody specialising in fluvial sedimentology above degree level, but the depth of research would not make it suitable for quick reference.

Rosemary Darby BA Hons(Open),
BSc.Hons (Open), Certs Ed. (UK, NZ)

Petrology of Millstones

Tony Browne

Before the introduction of roller mills and large-scale production methods toward the end of the 19th century, millstones in corn mills powered by water or wind, ground flour and animal fodder. Mills were recorded in Domesday, so certainly pre-date the 11th century.

Today the types of millstones and methods of working can be seen in a number of carefully restored mills, often open to the public. Two large cylindrical stones mounted horizontally, one above the other, are used to reduce wheat or other cereal to flour or other consistency. The upper stone, or runner, is rotated by linkage from the primary driving mechanism, over the lower bedstone, which is static. Both stones are encased in a wooden housing.

Grain is fed down through an opening, the eye, in the centre of the runner, to pass spirally between the stones, which are set very close when milling, and out through the periphery to be collected. The working face of the runner is slightly concave.

Rock required for millstones must be strong, not easily cracked, with a degree of coarseness and good wearing qualities. Advantages would be if it were obtainable in quantity and with easy access to the rock face.

While rock from various locations in Britain was used, the greatest quantity was that quarried in the Derbyshire Peak District from Namurian strata of the Upper Carboniferous, known as Millstone Grit. This is a coarse-grained sandstone which was readily accessible on the moorland ridges, and an important millstone manufacturing industry developed there. These stones, known as "Peak" stones, have been used extensively throughout Britain and were regularly exported.

Tucker (1977) gives a list of other quarries and the types of stone used. These include:

The Forest of Dean; Devonian conglomerate

Penallt, Gwent; Devonian conglomerate

Glenstocking, Kirkcudbrightshire; granite

While the above stone types were adequate for animal fodder and oat milling, difficulties arose with the milling of wheat for human consumption. A wheat grain comprises three components, the outer husk or bran, a small wheat germ and the bulk of the interior a starchy endosperm (Figure 1). The last of these consists of semolina (coarse), middlings (intermediate) and finer particles.

Approximate composition is: 85% endosperm; 2.5% wheat germ; 12.5% husk (Jones 2001)

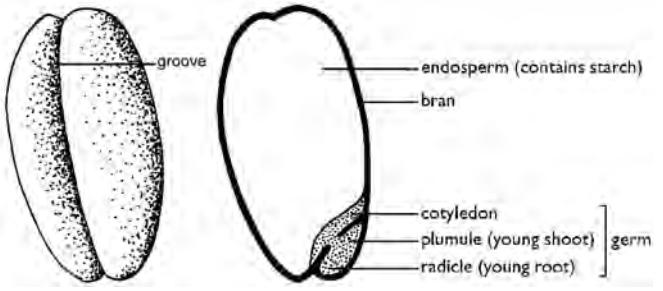

Figure 1. The anatomy of a wheatgerm. © Mike Redfern.

Where all components were used, i.e. for wholemeal, there were problems of storage due to rancidity and mildew. Because of this and fashionable personal digestive preferences, white flour with the bran and wheat germ removed, acquired a higher status. What was needed was a pair of stones that could shear off the bran, separate the wheat germ and grind the endosperm.

As the resulting "meal" passed out of the stones it was swept into collecting apparatus and sieved to produce the flour. In earlier times cloth was used to sieve, but later, wire or silk. The separated germ and bran would be used for animal fodder. A wheat grain with a central groove along one length (Figure 1) and a sticky wheat germ is not easily separated, and the above rock types are too abrasive to perform satisfactorily.

Milling is improved by "dressing" the stones. A series of radial right-angled triangular furrows is cut into both the runner and the bedstone such that grain is subjected to a shearing action between the sharp edges of the furrows.

However the most efficient rock for milling purposes came from quarries in the Paris Basin, chiefly at La Ferte-sous-Jouarre, where a very large millstone-making industry was in existence from before the early 15th century when it was recorded in deeds (Ward 1993).

This stone is a whitish to yellowish, very hard recrystallised quartz from Tertiary deposits. It is known in France as silex and was often called "freshwater quartz" in Britain. The structure is chert-like in parts and granular in others. There is a series of small cavities throughout the rock to give a natural shearing action, and as the stone wore down new pockets would be exposed.

The stone in the now infilled quarries was found in layers within bands of clay and sand. Although the early days of quarrying are known to have produced large enough blocks for monolithic millstones to be formed, as in the case of Peak stones, subsequent manufacture had to make use of smaller pieces, as large pieces were no longer available (Ward 1993). A number of these, possibly ten or more, were shaped to fit, cemented together and bound with iron hoops around the circumference to prevent break-up (Figure 2).

These millstones have long been known as French "burrstones". Records show that they were introduced into Britain in the 16th century, possibly earlier (Ward 1993). While the natural qualities of this stone would have given good results, millwrights would later have the faces dressed for better separation and transport of meal through the stones.

It was common in working mills (and this can often be seen at those which have been restored) for there to be at least two separate sets of working millstones, one pair of Peak or more local stones for animal fodder, and a pair of French burrstones for white flour. The working faces of all millstones have to be dressed regularly due to wear. The harder the stones the longer the interval between them being taken out of service, another plus for burrstones.

Figure 2. Segmented and banded French burrstone showing the vesicular nature of the stone. The iron piece let into the centre of the millstone is yoke-shaped; named the "rynd" it is only found on a runner and is the means of connection to the drive shaft. The stone in the foreground has three iron bands whilst the one in the rear only two. © Brian Fairhurst.

Some size comparison can be made between Peak stones and French burrstones:

Early French burrstones	diameter	1.8 - 2.25m	(~ 72in - 90in)
	depth	36cm	(~14 in)
Later French burrstones	diameter	1.2 - 1.4m	(~47in - 55in)
Early Peak stones	diameter	1.5 - 1.8m	(~60in - 70in)
	depth	36cm	(~14 in)
Later 19th century Peak	diameter	1.2m	(~48in)

The thickness of the stones obviously decreases over time with wear until they were no longer of practical use. French burrstones started life with three iron bands around the circumference and were used until there was only one. This is the reason for discarded burrstones often seen leaning on mill or farmhouse walls having the single hoop (Figure 2).

The smaller Peak stones would have a greater rotational speed than the burrstones.

Burrstones often have a manufacturer's metal nameplate fixed into the back of the stone. From these it is known that while these were sometimes imported into Britain from France, more often separate pieces were brought in and the millstones made up here. This resulted in a partial shift of millstone manufacturing from the quarries to port areas, such as London and Liverpool.

Another millstone type imported into Britain was made from vesicular basalt from the Eifel region of Germany. The hardness of this rock containing an abundance of small vesicles gave sharp cutting edges. They were monolithic and shipped through Cologne, a corruption of which led to them being known as "Cullin" stones. In milling quality they were said to be better than Peaks, but worse than burrstones, and were used for white flour.

Prices of millstones varied considerably over the many years of manufacture. Tucker (1977) gives prices for some of those made by the Corcoran company of London between 1878 and 1895. Burrstones £15 per pair for 3ft 6in of lesser quality; £40 per pair for 4ft 6in best quality; Peak stones £5 6s 0d for 4ft diameter.

Production of burrstones made in Britain then was approximately 3,000 to 4,000 per annum. The number of British millstones made would be much greater, not only because they wore more quickly than the burrstones, but there was an export industry to be supplied.

An interesting type of millstone to be seen in the North Midlands of England is made from sections of Millstone Grit, cemented and iron bound as French burrstones. These have long been known in the trade as "Mow Cop" stones (Watts pers comm.). Mow Cop is a folly- topped hill on the Cheshire/Staffordshire border with disused quarries in Namurian strata. All the Mow Cop stones located so far are at mills within a short distance of the quarries. Care has to be taken in this area to visually distinguish between the two types of stone. The more obvious sign is that Mow Cop stones have fewer segments than burrstones, usually from 3 to 7, but closer examination reveals the different nature of the rock.

The question as to why these stones were made in this way has been raised for some time, as normally Peak stones are monolithic. A visit to the Mow Cop quarries shows heavy faulting throughout the quarries, with associated barite mineralisation. Incipient fractures within the rock will cause splitting when worked, so it seems very probable that frustrated masons might well join the pieces together rather than start again with similar results. This faulting is not apparent in Peak quarries visited by the author (Browne 2005).

Support for the above theory is found in the writing of Robert Plot in "The Natural History of Staffordshire" (Plot 1686). The Mow Cop quarries were active at this time and Plot recounts how the rock frequently breaks:

"which it so frequently does not withstanding their utmost care, that there is but very few of them that are not made up of two or three pieces, thus bound together with a hoop; nay so very subject is it to crack and flaw, that whenever it happens that they may finish one intire (sic) yet it must be bound about thus with an an Iron hoop to remain upon even in the Mill, to preserve it from falling asunder in the motion".

Attention is often drawn to a couple of half-finished millstones "in situ" in the faces of the Mow Cop quarries, as proof of millstone manufacture there. However, not only would millstones have been made from blocks cut from the quarry walls, but the rock is so weak at these points and the "stones" are cut across the bedding, it is obvious that, like the folly on the mound above, these features are purely ornamental. As are most of the chiselled "arcs" fashioned into the quarry walls.

The property is in the hands of the National Trust and well worth a visit for the geology and the views.

Millstones formed from mica schist have been found. These were usually smaller stones measuring about 0.8m by 0.1m (32in by 4in). One such pair is held at Buxton Museum in Derbyshire. While mica schist would seem most unsuitable for milling purposes, the schist used is highly garnetiferous, giving many sharp cutting edges, and like the burrstones, as the millstones wore, fresh cutting edges were continually exposed. It is said that such millstones were made in the Hardanger area of Norway in historical times and later in Foula on the Shetlands. They were probably used for milling oats as wheat did not grow so far north.

In the late 19th century some manufacturers also made composition millstones. These might be from crushed burrstones or carborundum, cemented with a mix of calcined magnesite and diluted magnesium chloride (Tucker 1977).

Plot (1686) refers to millstones also being made from glacial erratics. He writes of great round pebbles being found on Staffordshire heathland, "some pebbles so vastly great, that as I was told, there have 3 mill-stones been made out of one of them". He writes that these millstones were used for "grinding wheat, and some think them not short of the Colen (Cullin) stones". From this it would appear that the erratics are not local sandstones. The glacial deposits in this area, as in Cheshire, came from a north-west direction. The largest stones now found are andesites from the Borrowdale Volcanic Series, and smaller granites from the Lake District or south-west Scotland. An andesite does not seem a likely candidate for a millstone, and I know of none which have been recorded. The granite erratics found today in this area are not large enough for millstones; could it be that those suitable have been used over time? A granite millstone can be seen outside the Cheddleton flint mill in Staffordshire, although this would not have been used at this mill. A section of dressed granite millstone has been located in Cheshire, the source of the rock almost certainly south-west Scotland.

There are many Peak millstones to be seen near old quarries in the Derbyshire moorlands, for example below Surprise Edge above Hathersage. Many of these are perfectly finished but never sold as the industry collapsed in the last quarter of the 19th century. Care should be taken to distinguish between these and the other finished stones which are smaller in diameter, and were actually made to run vertically as pulpers or grindstones in industry but again, never sold. Local mythology has it that the collapse was due to recent importation of cheaper French stones. However as can be seen above, French burrstones were more expensive and had been imported for centuries.

The real reason was that the industrial revolution had caught up with the milling industry, and new techniques were introduced using rollers and other mechanical devices in large mills allowing greater production of flour necessary for an expanding population.

It is interesting to note that the production from a given quantity of grain using the best millstones can be approximately 80% but with a little bran. A modern roller mill produces about 80% very white flour (Jones 2001).

Acknowledgements:

Thanks to Mike Redfern for Figure 1 and information on milling; Brian Fairhurst for Figure 2 and to Fred Broadhurst for joint examination of the Mow Cop quarries.

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ISDR*-UNESCO workshop on urban policies and decentralisation: Addressing the 'big issues' in increments: an international approach to trans-disciplinarity and decentralisation for sustainable development

Annette Kimmich, Open University Geological Society Mainland Europe (OUGSME) and Commission for Groundwater-Seawater Interactions (CGSI)

Abstract

Global communities are becoming more vulnerable to geo-disasters and impacts of climate changes on all continents of the Earth. In recent years many geo-disasters have affected society in different parts of the world. The tsunami in the Indan Ocean left a vast area devastated and populations lacking basic needs. Even if the cause is known, the environmental and social impacts of this event have resulted in huge problems that can only be addressed if experts from many fields work together. Despite the extent of damage and destruction, not all problems are common to all areas. For this reason, regional transdisciplinary efforts can lead to solutions that are of great value to distant communities with similar problems, but not necessarily to their own neighbours. Geo-disaster impacts in urban and rural zones can be mitigated through decentralisation. This presentation highlights some of the problems and their local aspects and one international effort to combine expertise to facilitate remediation in different areas with varied scenarios. The presentation also explores the issues concerned with achieving environmental, social and economic sustainability through corporate strategies for disaster management education for the affected communities in urban and peri-urban regions on global, national and local level through decentralised responsibilities.

Introduction: A natural event, an international catastrophe

On 26 December 2004 a natural phenomenon occurred that changed the world as we know it and for some people much more than for others. As I watched the tsunami drama unfolding around the Indian Ocean, many thoughts went through my mind and I found myself in an emotional conflict situation. On the one hand, with my interests firmly embedded in Earth Sciences, there was excitement that such an event was made visible to all through media coverage, especially in a field that determines time in millions of years, where 10 000 years is regarded as 'yesterday' or 'tomorrow' and where processes unfold slowly and gradually. This was a 'once-in-a-lifetime' event that would give insight into little-known dynamics and determine the extent of damage that could be expected; in short, the basis for widespread research and a true opportunity to move forward. On the other hand, there was the horror at the dimensions of human suffering (Figure 1), the realisation that what had happened in a few hours would need years of hard, targeted work, to rebuild infrastructure and existences, to alleviate pain, to dispel fear and to make support available.

And I was angry too, angry at missed opportunities and the breakdown of simple communication channels that may have saved many of those lives. The means were available but were not implemented as they could have been, through lack of insight, limited views of capabilities or competencies and the fact that global electronic communication was not being used optimally, that nobody had had the foresight to realise that a warning system, no matter how simple, was on our very doorstep.

Figure 1. Death and destruction after the Indian Ocean tsunami, 26.12.2004 (by kind permision of Barbara Earth, Philippines)

Countries on the Pacific Rim have a tried and tested communication network that enables warnings to be sent quickly and effectively. As soon as seismic events are recognised and assessed for their hazard potential, the system is operational, and countries receive communiqués of possible consequences and recommendations are made. The hub of this network received the earthquake signals, determined the location and magnitude and sent its messages to say that a tsunami hazard for the Pacific countries was very unlikely – but that is where it stopped, at least for the moment. That the consequences of such tectonic plate movement were likely to be experienced outside the Pacific area was not taken into consideration fully. No warnings went out via, for example, diplomatic channels to embassies in countries lying in the paths of the deadly waves. Here was a missed opportunity to convey warnings via radio and television that could have alerted populations to impending danger and advised an immediate evacuation to high ground or further inland. And what of the tourist areas: the hotel complexes that broadcast their advertising globally via the internet? Here was also a missed networking opportunity to pass on important information, and the jungle telegraph would have done the rest. Even if it had been a false alarm, a few hours discomfort would have been a small price to pay compared to the loss of life that finally resulted.

But despite all this and considering how easy it is to pass judgements from the comfort of my own non-affected home, I firmly believe that even the greatest of tragedies can have its positive

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aspects, and here was an opportunity to learn and to develop, bringing in knowledge and experience from many different fields, a signal as it were to encourage people to work together and to pool ideas, to see the complete picture.

Seeing all sides – essential dialogues

In the case of the tsunami events, to which I will return later, we see a problem with a centralised system and defined boundaries, coupled with the fact that simple principles of communication were not implemented. It may be that any action that could have been taken lay beyond the bounds of strict regulations, that flexibility as a defining factor was not considered, that a chain of command had to be adhered to, and I do not wish to blame anyone or any organisation for shortcomings, but merely point out that there is room for improvement, to learn from mistakes. It may have been a trans-disciplinary communication problem. There are many possibilities for how and why a possible solution was not considered. But taking the communication across disciplines as a possible important factor, just how much do we talk to each other? My son is a doctoral student of the humanities, my daughter an undergraduate in the realm of social sciences. When I attend a university function I am often introduced as 'my mother, the student' with the qualification, 'but she is into Natural Sciences so you won't be able to talk to her'. Of course, this is only meant as light-hearted banter, but is there some truth in this, some underlying boundary that has been arbitrarily fixed? Do I really have nothing to say that would be of interest, or have little understanding of the material with which my children and their colleagues work? Perhaps it is a language problem. Scientists have languages all their own which they use with ease amongst colleagues, but is there difficulty in expression when it comes to simple explanations?

If we imagine now an Alpine meadow surrounded by majestic peaks: the language student may be lying on the grass composing a poem to embody the beauty of the scenery; the social scientist may think about the economic problems of upland farming or the social disadvantages of high Alpine communities compared to their compatriots in urban centres, whilst the Earth scientist is contemplating the processes that formed the landscape and pushed the seafloor up to such altitudes, all very different scenarios, but with a common denominator, the meadow and its mountains. We are all looking at the same thing from different perspectives and each of us can learn by listening to the ideas of the others; a holistic view that goes beyond the rocks and Alpine flora. In the depth of contemplation, I may have missed the beauty of my surroundings, the simple wonder of being, and any advantages or disadvantages that result from my rocks being where they are in the form they are. The others may not have considered that without the processes of tectonics, burial and uplift, they would not have the natural beauty to write about and those upland farmers would be somewhere else with quite different problems. Therefore, communication across disciplinary boundaries must consist of both giving and taking, talking and listening and attempts to combine the information for other uses. This example merely represents a generalised attempt to define the common ground. However, it does illustrate, if transposed to the problems with which we are confronted, the point made by Helga Novotny (2003) in her paper 'the Potential of Transdisciplinarity' – if joint problem-solving is the aim, then the means must provide for an integration of perspectives in the identification, formulation and resolution of what has become a shared problem.

The 'big issues': from little acorns …

Globally we are confronted with many problems: poverty, disease, starvation, pollution, limited water resources, to name but a few. We are aware of these problems and many governments and international organisations have launched programmes to tackle them in a global or national context. These are all worthy causes, but where does the problem-solving begin? Does it start at the top and must we expect our politicians and benefactors to grasp the details at the bottom, the level where most of the affected can be found. How many of the top-level decision-makers know what it is like to fight constantly for survival, not theoretically but in a practical sense? Who would know better than the people themselves what hardships they have to bear and who is in a better position to tackle the problems where they arise? If you are a gardener, then you will know that if you do not tend to the roots, they will not develop into healthy and productive plants. The plant itself is designed to develop in a certain way, but without a few basics like water and nourishment it is helpless, yet give the plant the essentials for life and it will flourish and multiply.

If I have no food on my table, it is no great comfort to me to know that my neighbour also has no food and that someone far away has recognised my problem and is working on a scheme to give me the food I need. It is also no great comfort to be given food for one day and not know where it will come from tomorrow. What I need is a possibility to find a long-term solution together with my neighbour and his neighbour and everyone else in my region suffering from the same problem, with the help of local authorities and institutions in the same position and using all the local infrastructure available. This gives me hope. I can ask for expert outside help without making the task too complicated and I am in a position to help this expert, because I understand the local laws and regulations, can speak the local language and can integrate knowledge on culture and religion that may become very important when planning remediation processes. Not only this, I am saving time and money by using the local resources, both of which are important factors in a time-dominated world where financial support is limited. This way there is less bureaucracy. At the same time I am learning from the expert and gaining knowledge, some of which may be useful in other areas, provided it is recorded and made available.

Educational aspects can be exploited in training on-the-spot task forces to tackle specific problems, which in turn will be able to work together with local agencies and authorities to address issues from different perspectives. Here interdisciplinarity comes into its own.

An organisational concept for interdisciplinarity and decentralisation

Several years ago I was asked to devise an organisational concept for the then International Association of Hydrological Sciences - International Association for the Physical Sciences of the Oceans (IAHS-IAPSO) Commission for Groundwater-Seawater Interactions (CGSI), based on my experience in setting up and running the Mainland Europe Branch of the Open University Geological Society; a Society set up to help students studying Earth Sciences with the Open University of the United Kingdom. This branch was to be a millennium activity, going forward to new dimensions in recognising the members living outside the UK and Ireland. We were given a year to found our new branch

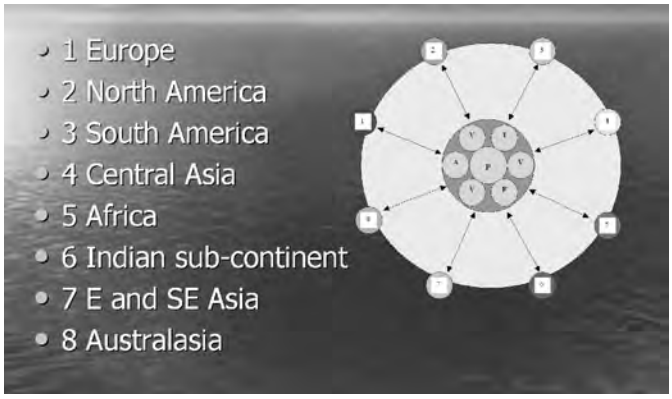

Figure 2. The structure of CGSI: organisational nucleus, eight regional sub-groups.

and being far from the constraints of the mother institution, we had a white canvas to practise our ideas. Being so spread out, the only way this could function optimally was to base it on electronic communication and so integrate every single member no matter how far afield. We had the interest and the expertise needed. Our branch was to have a flat organisational form, with a nucleus of members providing the services and co-ordinating activities, but with every member having the possibility to submit ideas and, if accepted, given the autonomy to undertake whatever was needed to put these ideas into action. And so we were able, within three months, to launch our own website and produce an electronic newsletter, facilitated by the members who were only too willing to contribute. Six months after receiving our mandate, we were fully operational and held our inaugural meeting. The experience gained in these past few years has allowed us to optimise processes by using our resources where they are. Meetings and excursions are organised by local people, with local knowledge and contacts, allowing us to budget to rock-bottom prices. With every new activity we produce written information for our library, which can be distributed electronically if requested. We receive a small grant, but this is all used for the benefit of every member, and running costs are kept to an absolute minimum as our committee meetings take place via e-mail, which has never been a disadvantage. The setting up of the organisation of our branch was watched with interest by the other branches, especially our use of electronic communication. Gradually other branches have moved to producing their own electronic information in the form of newsletters and websites and see the advantages of using local expertise. And this was to be the basis for the Commission.

CGSI is much larger, but the basic principles can be adhered to. A nucleus comprising a president as Commission representative to other organisations, two to three vice-presidents, a treasurer and an executive secretary, which co-ordinates activities and disseminates news and information to the eight geographical sub-groups (Figure 2). Members consist of oceanographers and hydrologists, engineers, managers, NGOs and governmental representatives from 48 different countries. Although many members are committed to international research that is not area-specific, the basis has been provided for each regional group to suggest activities and request expertise. Again, using local people with experience, we can, effectively, help to put together a working group with any external expertise needed. Local groups can profit from expertise that may be missing locally and experts can profit from local knowledge regarding legal aspects, infrastructures, culture and customs, which facilitates planning and implementation. It also saves time and money. If a specific problem arises in a specific area, the Commission can consult its lists to find people on the spot and experts who are nearest, without having to go through the procedures of putting together an international team that will use a good part of its finances for travelling, and again, using the advantages of electronic communication, news and information can be distributed quickly and effectively with a minimum of bureaucracy. Being bound by a common field also facilitates Commission meetings, as members often visit the same conferences, which, to date, has enabled annual meetings to be arranged without incurring additional costs for travel and meeting rooms.

This system is in a phase of re-organisation, and the potential of regional groups has not been fully exploited. But now I return to the tsunami and the devastation caused to illustrate how this can work. Geological systems can be very localised. A geological or environmental problem may affect one village or a group of villages, but a few tens of kilometres further and conditions are completely different. The December tsunami changed coastal environments dramatically. Encroachment of seawater into freshwater sources contaminated water systems that may take hundreds of years to revert to normal. Freshwater supplies are therefore unavailable or depleted for the local population. Contaminated water supplies can lead to the spread of disease in a population already weakened by its limited food resources. Saltwater corrodes mains and can render distribution systems unusable. New sources have to be found, distribution systems installed. Local water resources may have to be treated. Assessments as to the extent of the problem should be undertaken by hydrologists and geo-chemists. Geologists can help to search for new sources. The geo-experts can assess the problems and can give recommendations, but input and expertise on how the infrastructure has to be changed or completely renewed must come from others. There are constructional aspects, legal aspects, politics, regulations, funding, all these have to be taken into consideration and they all need local knowledge and transdisciplinary input. The natural scientist and the social scientist must work together, must communicate and listen to find the optimal solutions. All perspectives have to be considered. A local knowledge-base results, which serves as the defining aspect for decision-makers. But this local knowledge may be quite ineffective further along the coast, where farmers have lost productive land that has become salt-marsh, where assessments on damage and environmental changes must be undertaken anew and different solutions found. However, the knowledge gained in the first example may help a community thousands of miles distant with similar geo-problems, but with quite different infrastructure, local policy and regulations. And so we see the difficulties to generalise, as each environment has its own baseline. But gathering information and finding solutions in this decentralised manner brings experience that can be transferred and developed in other areas: a snowball effect. And knowing the manifold problems and how quickly conditions can change, planning for the future has to include sustainability, to use our resources wisely and in such quantities that they do not become depleted.

First efforts and first results

CGSI included provisions in its programme for 2005 to contact its members around the Indian Ocean with the intention of forming a

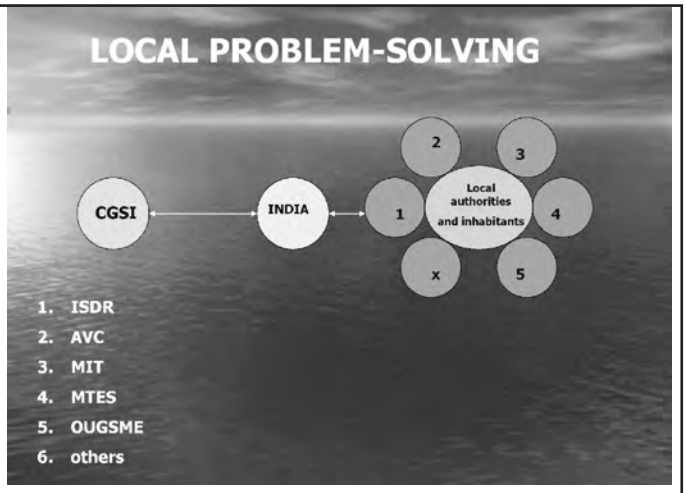

Figure 3. Local problem-solving: the cluster addressing tsunami problems in Tamil Nadu, India (1-5: participating organisations).

task force to investigate problems resulting from the December tsunami, to aid mitigation planning in affected areas and to educate young scientists to form a basis for sustainable solutions. With this aim freshly introduced straight after the occurrences, we were very pleased when, in January, a message came in from a CGSI member in India requesting help in the Tamil Nadu region to set up mitigation concepts. This was the possibility to put theory into practice and we readily agreed to support the Institute for Sustainable Development and Research, ISDR, the co-organiser of this workshop, with any help that might be needed (Figure 3). Since then we have been working together, with a great effort being contributed from the Indian side. Two months after our first contact, and with a further partner, the A.V.C. College of Engineering, Mayilduthurai, Nagai District, Tamil Nadu (AVC and AVCC), a workshop was organised to discuss the problems and form task forces to assess the problems, all with local participation and scientists from various fields, including the social sciences. Meanwhile CGSI put the basic idea forward to its mother organisation, the International Association for the Physical Sciences of the Oceans (IAPSO), which agreed to endorse the effort. A further contact with the International Tsunami Commission gave us the go-ahead to take the lead on their behalf for this action. The first workshop was well subscribed and first groups are working on specific problems to formulate projects to be submitted to various funding agencies. Here CGSI can also be of assistance by including the water problem's aspects and training possibilities for young scientists as well as providing partners for funding programmes that require an affiliated partner or an international element, for instance, the EU programmes. Concurrent to the first workshop and thanks to the generosity of AVCC, a Tsunami Resource Centre was officially opened in AVCC premises. For two month's work I regard this as a great achievement and admire the Indian partners for their resourcefulness. The next workshop is planned, with yet another partner, the National Institute of Technology, Kurukshetra joining the consortium and taking over the organisation for this now national event. And so, to date, the idea of supporting local organisations in a concerted effort to address regional problems has had a very positive start and received an encouraging echo.

At a meeting between myself and ISDR and partners in Bonn last October, a general outline of ideas was discussed and I hope, in the near future, to be able to visit Tamil Nadu to see the problems for myself and assess the mitigation possibilities discussed.

Figure 4. Flooded historical Old Town of Bern, Switzerland, August 2005.

As already mentioned, the tsunami event took place on 26 December 2004, but it was by no means the only natural hazard to manifest itself in recent months. Floods occurred in the Mumbai area of India in July 2005 as well as in a large area of Europe (Figure 4). Alone in the region of Bern, Switzerland, thousands of homes were damaged or destroyed. Some of the evacuees will never be able to return to their land and rebuild. In September, the effects of Hurricane Katrina (Figure 5) destroyed a large part of the city of New Orleans and left thousands homeless. In October a major earthquake devastated parts of Kashmir, again leaving thousands of people without shelter and basic needs to face a harsh mountain winter (Figure 6).

And this list is by no means complete. In media coverage we have seen the effects on a large scale, but behind the pictures and news reports are many individual fates, loss of family members and friends, unemployment, loss of housing, devastated local infrastructure, lack of food, clothing, medication.

Figure 5. Aftermath of Hurricane Katrina, September 2005.

Figure 6. Kashmir earthquake, October 2005 (photo courtesy of Islamic Relief).

Whereas governments can help on a national scale, immediate and uncomplicated help needs to reach the victims. Aid organisations provide the first necessities – water, food, shelter and disease-prevention requisites. But what happens afterwards, when the events have vanished from the world news? This is the question we are trying to address in planning remediation efforts to apply management schemes, rebuild infrastructure, improve water supplies and sanitation, set up information networks, reduce risk and educate those most likely to be at risk from all natural catastrophes…

AND THIS AT LOCAL LEVEL!

A handshake from a dignitary surrounded by a group of bodyguards does not fill empty stomachs, nor build houses or clothe children and neither do the press reports of such visits. The problems need real hands-on, rolled-up-shirt-sleeves work to solve them.

Future perspectives

Charles Lyell (1830) stated, as every geology student knows, that the present is the key to the past, indicating that what we see today provides the evidence of processes that occurred long ago, but the tsunami event teaches us that the present is also the key to the future, as it has left us with new problems for which solutions must be sought, solutions, we are told, that should make the world a better place for future generations. However, the next future generation is being born now, today, and has a right to the best possible conditions for living in our changing world, which is why there is no time to lose. Although the problems seem endless at present, we are offered a chance to build from past experience and learn from new, not only to mitigate and repair, but to do it on the basis of sustainable development to improve the quality of life long-term.

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Annette Kimmich is the Mainland Europe Branch Organiser. She gave this talk at the UNESCO International Forum on the Social Science – Policy Nexus: Social Sciences, Social Transformations and Social Policies in Rosario, Argentina on 20-24 February 2006.

Book review

Volcanoes and the Environment edited by Joan Marti and Gerald G J Ernst, 2005, Cambridge University Press, 471pp, £50.00 hardback, ISBN 0521592542

This book contains contributions from volcanologists from around the world. In the Preface the editors point out that they have taken a broad view of the environment, including the impacts of eruptions on human health, societies and economies as well as on the atmosphere, climate, flora and fauna.

The first three chapters cover the physical behaviour of volcanoes, volcanic hazards and prediction of eruptions starting with basic geology of the Earth's interior, plate tectonics and volcanism associated with plate boundaries and hotspots: everything is clearly explained with good diagrams. In Chapter 2 we read that ten per cent of the world's population live within close proximity to active or potentially active volcanoes: some successes and failures in volcano-hazard mitigation and the challenges facing volcanologists are discussed. The third chapter deals with volcano monitoring and forecasting.

The contribution of volcanoes to shaping our planet and its environment and the role of plate tectonics throughout the history of the Earth is covered in Chapter 4. Chapter 5, written by Stephen Self of the OU, deals with the main mechanisms by which different styles of eruptions can affect the atmosphere and climate and gives examples of the atmospheric effects of super-eruptions and flood basalt events.

Chapters 6 to 9 explore the relationship between volcanism and life, covering primitive life forms today and how they relate to volcanism and their relationship with other species in evolutionary history; mass extinction events which may be related to the eruption of flood basalts; the impact volcanic eruptions have on vegetation; and Chapter 9 deals with the impact on animal communities with emphasis on the colonisation of arthropods following the 1980 Mt St Helen's eruption.

"Volcanoes can hold a deep fascination" are the opening words of Chapter 10 - I found this chapter particularly interesting, containing as it does details of some famous eruptions, including Nevado del Ruiz in 1985, Mt Pinatubo in 1991 and Soufrière Hills in 1995. Some of the lessons for human health and survival from eruptions are discussed, with descriptions of the different hazards associated with dormant and active volcanoes.

Chapters 11 to 13 cover in turn the beneficial effects of volcanoes: geothermal energy, valuable ore deposits and industrial uses of volcanic materials.

The last two chapters discuss the relationship of volcanism with human societies and the impact on the economy.

Each chapter ends with several pages of references: there is a good index but there is no glossary although many geological terms are explained in the text. The black and white photographs and diagrams are clear and well annotated.

Spanning a variety of topics from geology to climatology and ecology, this very readable book will appeal to a wide range of readers interested in earth science, geography, ecology, social science and environmental issues.

Elizabeth Maddocks BA (Open)